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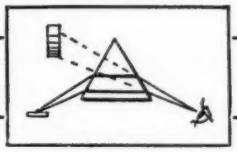

FEBRUARY
1934

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Young's Experiment with Newton's Rings

W. W. SLEATOR AND A. E. MARTIN, *University of Michigan*
(Received November 6, 1933)

IN attempting to repeat Young's famous experiment, in which he interposed a layer of oil of sassafras between a lens and a plate, of different kinds of glass, an unexpected difficulty was encountered. The lens used as the upper glass had the index of refraction 1.53 for the green light given by a mercury arc with a filter. Oil of cassia was used for the liquid, its index as found by a hollow prism being 1.62. The third medium was a lead glass prism whose index was carefully measured by the minimum deviation method and found to be 1.72. With this combination the interference pattern as seen by reflected light, with incidence normal or not, had a dark center. This center was as dark as the dark rings, and as dark, relatively to the rest of the pattern, as the center of the ring system observed with air between the glasses. This was an unexpected result. Fig. 1 shows the ring system, air on the left and cassia on the right, the latter showing closer rings. The exposure times were 40

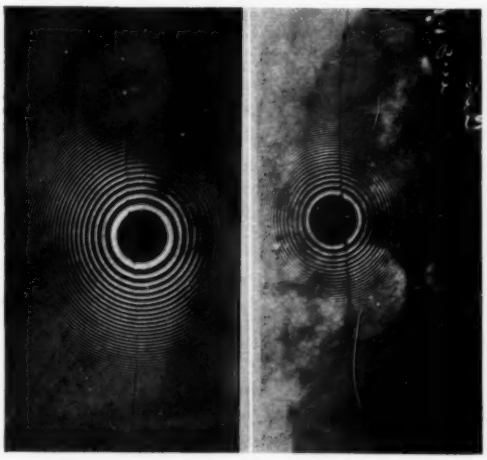

FIG. 1. Newton's rings between a lens of index 1.53 and a prism of index 1.72, photographed by reflected light, $\lambda = 5461$A. On the left, air between the glasses; on the right, cassia oil, index 1.62.

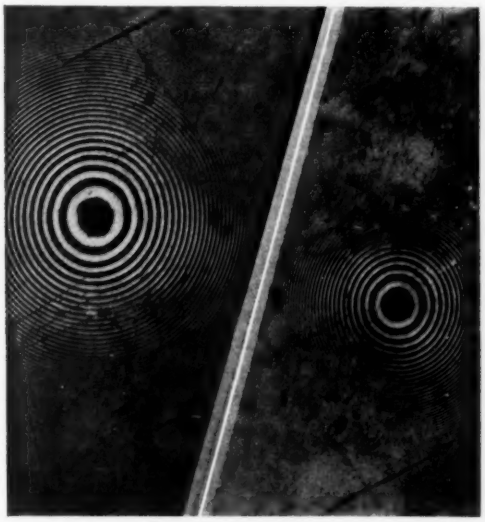

FIG. 2. Newton's rings, conditions as in Fig. 1 except that the surfaces were not so firmly pressed together.

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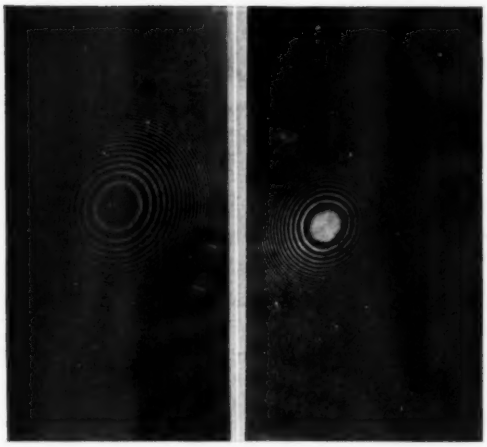

FIG. 3. Newton's rings showing on the right the bright center with cassia oil and a freshly ground and polished surface on the second glass.

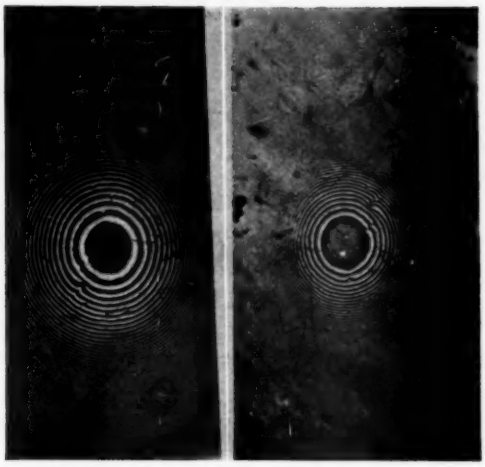

FIG. 4. The rings with indices 1.53, 1.62 and 1.78 in order; the center not dark but not perfectly bright.

seconds for air and one hour for cassia. The focal length of the camera lens was about 2.5 cm and the magnification is about 20. The center on the right is evidently black. Fig. 2 shows the same situation except that the pressure was less and the centers are smaller. The surfaces are somewhat marred but were carefully cleaned with xylol and otherwise.

On hearing of this result, Professor Monk of the University of Chicago suggested that anomalous effects might be due to old surfaces. We then ground and polished the end surface of our flint glass prism, and on trying again with the lens and cassia oil the center was found to be bright, indeed to be as bright as the bright rings—even brighter than Young appears to have observed. This effect is shown in Fig. 3, where again air is on the left.

The purpose of this note is to point out the remarkable influence of outer layers on the phase of reflected light, and to suggest the observation of interference effects as a possible means for the study of surface conditions. It seems that the effective index of the outside of the old flint prism was as low as 1.55 for if it had been very near to that of cassia (as was the case with some of our combinations) the rings would have been much fainter than they were. Fig. 4 shows the intermediate effect given when the third medium was glass of index 1.78.

The Characteristics of the Sodium Lamp as Influenced by Vapor Pressure

GORTON R. FONDA AND ANDREW H. YOUNG, *Research Laboratory, General Electric Company*

(Received December 8, 1933)

THE sodium lamp is the latest commercial development of the gaseous discharge. Although it has been under study in laboratories for years, it has only recently been brought to public attention. One of its early appearances was as the source of illumination for experimental highway lighting in Holland.[1] Another was at the 1932 meeting of the Society of Illuminating Engineers at Swampscott,[2] for illumination of hotel grounds and for lighting an experimental highway, as a demonstration of lamps made by the Research Laboratory of the General Electric Company.

Sodium is a metal having a melting point of 97°C and a correspondingly low vapor pressure, amounting to about 0.1 micron at 200°C. In order to attain a pressure at which appreciable generation of light may result, the sodium must be maintained at a temperature well above atmospheric. This is secured by placing the lamp within a clear, double-walled vacuum flask as a means of partially conserving the heat generated by the discharge and thereby attaining the desired vapor pressure. An inert gas is present in the lamp as well, for this serves as a medium in which the discharge can start. As the sodium warms up, the characteristic yellow glow develops and becomes predominant in five to ten minutes. At the end of fifteen minutes the light output has approached closely to its maximum value.

Commercial sodium lamps vary widely in shape and design. They are made for both a.c. and d.c. circuits and are in the form of both bulbular and tubular lamps. An outstanding feature in the characteristics of all types is the optimum luminous output that occurs within a certain range of current density corresponding to a lamp temperature of about 200°C. It is accompanied by a similar optimum in luminous efficiency. An illustration is given in the curves of Fig. 1 for an experimental a.c. lamp. This lamp consisted of a cylindrical bulb 6.3 cm in diameter, with a pair of electrodes mounted close to each end at a 15 cm spacing. Each pair was made of an oxide coated cathode mounted within an open molybdenum cylinder to serve as anode during the appropriate half cycle. A pressure of 1.5 mm of neon was introduced as well as the sodium. It is apparent that this dependence of luminous characteristics upon current, as expressed in Fig. 1, is due to variations in vapor pressure that result from added wattage input to the lamp.

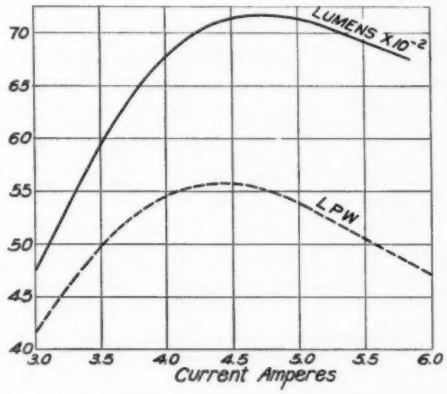

FIG. 1. Sodium lamp in vacuum flask. Variation of lumens and lumens per watt with current.

Because of this unique relationship with vapor pressure, the present study was undertaken with the aim of investigating the characteristics of the sodium lamp as functions of temperature and of current density. The lamp was placed in an electrically heated oven as a means of maintaining constant temperature. The wattage input to the oven's heaters was varied with changes in wattage to the lamp so as to maintain the desired temperature of the lamp as recorded on

[1] Electronics **5**, 253 (1932).

[2] Trans. I. E. S. **28**, 183 (1933).

a thermocouple having an area of 0.2 sq. mm, placed against the side of the lamp at a point midway. This, it is true, does not record accurately the temperature of the sodium, but at least there is a constant relationship between the two and apparently a close one, very near unity. The lamp had the same design as that described above, but was operated on d.c. as well in order that simultaneous readings might be taken with probes.

The expected cathode and anode voltage drops were found. The voltage distribution in the tube itself was found to follow a strictly linear relationship with distance along the axis of the tube, denoting that the light output was predominantly that from a positive column. The results of photometric measurements of the relative light output as a function of temperature are given in the curves of Fig. 2. They demonstrate that the optimum output obtained in practice at a specific current density, as exhibited in Fig. 1, is, in fact, a temperature phenomenon associated with 200°C.

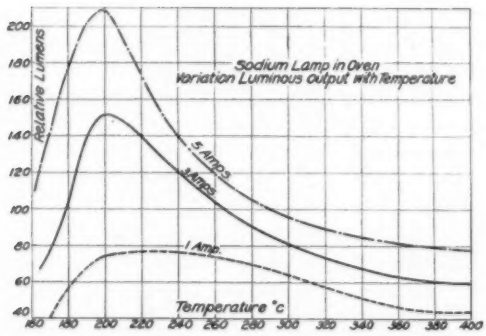

FIG. 2. Sodium lamp in oven. Variation luminous output with temperature.

Another feature brought out by Fig. 2 is that the light output per unit of current at any one temperature becomes proportionately greater as the current density is decreased. At 200°C, for instance, the relation holds

Light output at 5 amp.—42 relative lumens per amp.
Light output at 3 amp.—51 relative lumens per amp.
Light output at 1 amp.—74 relative lumens per amp.

This effect becomes very marked at still lower current densities. At 0.075 amp. and 265°C an arc efficiency could be obtained having a value of 315 lumens per watt. This represents 65 percent of the theoretical value for conversion of electric energy into light of this color. A similar result was found by Pirani.[3]

At temperatures above 200°C, the overall voltage across the arc fell off considerably. This decrease in voltage was participated in by all of the elements of the positive column, including the cathode and anode drops as well as that of the positive column itself. These changes are brought out in the curves of Fig. 3. They are

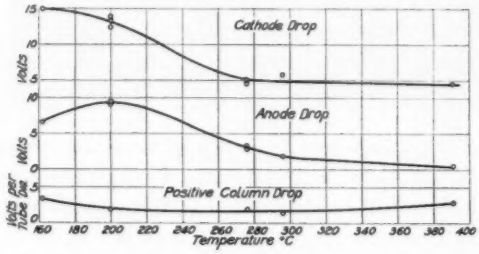

FIG. 3. Sodium lamp in oven. Variations in voltage characteristics with temperature at arc current of four amperes.

connected with a change in the fundamental character of the arc discharge. At temperatures above 240°C, the spectrum of the arc showed the sodium lines only, free from those of neon, denoting that in this upper range of temperature the electrical characteristics were predominantly those of sodium alone and were determined by its particularly low excitation and ionization potentials, amounting to 2.1 and 5.1 volts, respectively. Below 240°C the neon lines became continuously stronger in the spectrum, although not sufficiently so to affect the color of the light until the temperature had fallen to about 160°C. The electrical characteristics, however, were closer to those of a pure neon discharge, determined by its excitation potential of 16.6 volts.

Similar sodium lamps have been tested in the presence of argon instead of neon and also with sodium alone in the absence of a rare gas. With argon, the light output followed the same course as with neon and the efficiency of light output was of the same order. The anode drop and the drop in the positive column were likewise the same. The cathode drop was the same at temper-

[3] Pirani, Zeits. f. tech. Physik 11, 482 (1930).

atures above 280°C where, as already noted, the sodium arc characteristics predominate, but at 200°C it was of the order of ten volts instead of fifteen volts, showing the influence of the lower excitation potential of argon than that of neon. In the case of sodium alone, a stable arc could be maintained only at temperatures above 240°C. In this upper range, all characteristics were the same as in the presence of neon or argon.

From the standpoint of light output, therefore, it is apparent that in all cases there are two features in common, and of such importance that emphasis can well be placed upon them. These are the occurrence of higher efficiencies for any one temperature as the current density is decreased; and the existence of a peak in light output for all current densities at a vapor pressure corresponding to the temperature of 200°C.

They can be explained qualitatively by considering the various energy changes that a sodium atom undergoes on collision with an electron. Those that give rise to radiation are, in the main, two—the resonance radiation of the *D* lines, giving the characteristic yellow light, and the infrared radiation, occurring at 8183A and at 11,382–11,404A. For this discussion, the 8183A radiation may be neglected, for its excitation would seem to be always under the same conditions as that of the resonance lines, so that the relative intensities of the two can be taken roughly as constant for changes in vapor pressure and current density.

Between the *D* lines and the infrared lines, 11,382–11,404A (denominated hereafter *IR*) there are, however, important differences. The excitation of the *D* lines begins at 2.1 volts but does not reach a maximum until 7 volts.[4] The available velocities of the majority of the electrons are limited to 16.6 volts, or less, determined by the fact that this is the resonance excitation potential of neon and in the presence of 1.5 mm of neon very few electrons will be able to acquire greater speeds. At this upper limit, however, the excitation of the sodium *D* lines would be only 10 percent less than that at the maximum. One can say, therefore, that pronounced radiation of the sodium *D* lines will be excited only by electrons of greater than 7 volt velocity.

[4] Haft, Zeits. f. Physik **82**, 82 (1933).

With the *IR* radiation, on the other hand, the excitation begins at 3.1 volts. It reaches apparently a maximum at 4 volts, judging from analogy with the related line 6160A for which there are data.[4] At 7 volts, the excitation, on the same premise, would be 30 percent less. The *IR* radiation, therefore, will predominate as the electron velocity falls into the lower ranges, especially those below 7 volts.

These considerations are to be taken in conjunction with what has been observed as to accompanying variations in electron velocity. For the present purpose this can best be considered as related to the electron temperature, T_e. This magnitude is a measure of the kinetic energy of the electrons. Its significance is similar to that of the temperature of a gas. With a gas, temperature determines physical characteristics, such as pressure; and chemical, such as reactivity. The term has therefore been applied to electrons as significant of their energy content or velocity and it denotes in their case the extent to which one may expect those changes to be brought about which are associated with electron velocity, such as excitation and ionization of atoms.

The measurements obtained for T_e at 4 amperes and for various temperatures are grouped in the curve of Fig. 4. The temperature is here

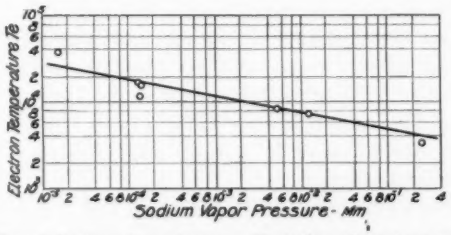

FIG. 4. Sodium lamp in oven. Variation of electron temperature in positive column with sodium vapor pressure in presence of 1.5 mm neon and at four amperes discharge current.

expressed as sodium vapor pressure to bring out the characteristic linear relationship that holds when the plotting is done on log-log paper. The decrease in values of T_e with increase in vapor pressure signifies directly that the average electron velocity decreases as the temperature is raised. Furthermore, similar measurements at lower currents showed that the average velocity at any one temperature increased as the current

density was decreased, down at least to 1 amp., the limit of the tests.

The application of these considerations can now be readily made. At any one temperature the proportion of energy radiated in the D lines should decrease as the current density increases, following the decrease in T_e, and the radiation of the IR lines should become correspondingly stronger. This change in relative output of energy would be brought about not only by the decrease in electron velocity, which favors excitation of the IR lines rather than the D lines, but also by the increased concentration of the electrons, which favors conversion of an excited sodium atom into the higher state before it can emit its D line radiation. In this way the decrease in efficiency of light output observed with increase in current density can be accounted for.

The other application has to do with the variations in characteristics observed with changes in temperature. An optimum light output was found for 200°C. The decrease noted for temperatures below 200° can, of course, be laid to the insufficiency in concentration of sodium atoms. The decrease in output for higher temperatures can be laid to the effect of higher vapor pressure, which, as already described, encourages the excitation of the IR lines at the expense of the D lines.

Application of these same considerations explains the variation of the spectral distribution of sodium, as recorded from measurements by E. Lax.[5] They show an increasing predominance of D line radiation that follows both reduction in vapor pressure of sodium and reduction in current density.

The significance of the results of Fig. 2 can be further appreciated by expressing the luminous output as a function of current density at constant temperature. This is done in the curves of Fig. 5 for four different temperatures. At the three higher temperatures, the curves show a noticeable characteristic in common—a linear portion initially for the lower range of current, followed by an exponential portion for the upper range.

[5] Krefft, Reger and Rompe, Zeits. f. tech. Physik **14**, 242 (1933).

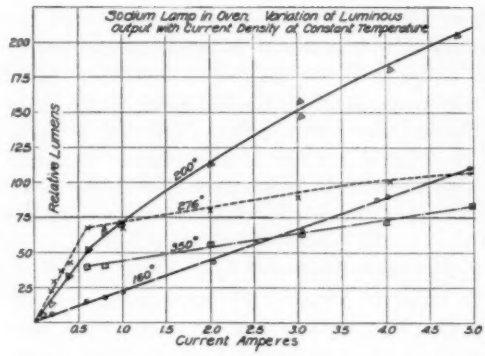

FIG. 5. Sodium lamp in oven. Variation of luminous output with current density at constant temperature.

The slope of the exponential curves decreases with temperature. It is 0.58 at 200°, 0.44 at 276° and 0.33 at 350°C. Its significance can be realized by expressing the results in the form of the equation

$$dL/dA = k(1-L)$$

in which L represents the luminous output and A the current. As the luminous output in turn is dependent upon the proportion of excited sodium atoms, this equation implies that the increase in lumens with increase in current is dependent upon the number of residual, unexcited sodium atoms represented by the expression $(1-L)$.

In the measurements at 160°C, as expressed in the curve of Fig. 5, there is a linear relationship between luminous output and current up to the limiting current employed. This implies that at such a low vapor pressure the generation of excited atoms capable of yielding resonance radiation is a linear function of the number of electrons constituting the discharge. At low concentrations of sodium atoms there is, of course, greater opportunity for electrons to acquire such high velocity between collisions that every impact will result in excitation of D line radiation.

In closing, the authors wish to express their appreciation of helpful discussion with Dr. Saul Dushman and with Mr. C. G. Found.

The Polarization of Light at Sea

E. O. HULBURT, *Naval Research Laboratory*

(Received November 29, 1933)

A polarizing prism properly oriented was found to darken the sea relative to the sky, to reduce the brilliance of the sun path and to render the horizon more distinct. In bright weather it increased the visibility of objects against the sea background. Attaching polarizing prisms to a sextant and to binoculars improved these instruments in certain cases. Measurements of the light of the sea ruffled by a breeze from several hundred yards from the observer out to the horizon several miles away showed that the light was often more, and rarely less, than 2/3 polarized with electric vector mainly horizontal but tilted up under certain conditions, e.g., tilted up 30° for the sun bearing 90° and at 45° altitude. From the observations and theory it came out that the sea light was the light of the sky at about 25° to 35° above the horizon reflected by the sea, the reflecting facets of the sea surface being most frequently at about 15° to the horizontal. The width of the sun path calculated from this was in agreement with the observed width of about 6°, 14° and 18° in moderate weather for the sun at altitudes 10°, 20° and 30°, respectively. The explanation is given of a number of breezy sea reflection phenomena.

I. INTRODUCTION

IT has long been known that the light of the sea and of the sky is a mixture of plane polarized and unpolarized light. The polarization of the sky light has been measured in detail for a variety of weather conditions[1] but the polarization of the light of the sea has never been investigated extensively. The present measurements of the sea light were carried out during a cruise along the Atlantic coast. The light of the surface of the sea was found to be strongly polarized and from the measurements there emerged explanations of the character of the sea reflection, the width of the sun path on the water and a number of familiar phenomena. Polarizing attachments to a sextant and binoculars were found to improve these instruments in certain cases.

The investigation has been limited to the rim of the sea, the region from the horizon to about 3° below the horizon which is the region from several hundred yards from the observer extending out to the horizon several miles away. This is shown by the scale alongside of Fig. 1a. The region comprises more than 99/100 of the total area of the sea within the view of the observer, if the observer is less than 1000 feet above sea level, and is the field of view of importance to the mariner or to anyone who looks out over the sea.

We have been concerned only with the sea ruffled by a breeze. For it was found that the optical properties of the sea surface, such as the brightness, color and polarization effects, remained approximately constant as the breeze increased from 5 to 25 knots. This may be regarded as the normal weather condition at sea. Two other possible conditions are a mirror calm sea and a sea pretty well covered with white caps, as in a breeze above 30 knots. These conditions were not very frequent and anyhow were of no interest, for they presented no unknown optical properties of the sea surface, the one being merely a smooth water surface and the other a more or less perfectly diffusing surface like a sheet of ground glass.

II. THE POLARIZING SEXTANT

In the case of the sextant, the altitude of the sun above the horizon is measured by bringing the image of the edge of the sun as seen in the instrument into contact with the horizon. The sea-sky scene in which the sextant observer is interested is the sea and sky at the horizon directly underneath the sun. And from this region stretching out over the sea toward the observer is the sun path on the water. It was found that

[1] Raman, *The Molecular Scattering of Light*, The University of Calcutta Press (1922); W. Smosarski, Gerlands. Beitr. z. Geophysik **38**, 97 (1933); and references *infra*.

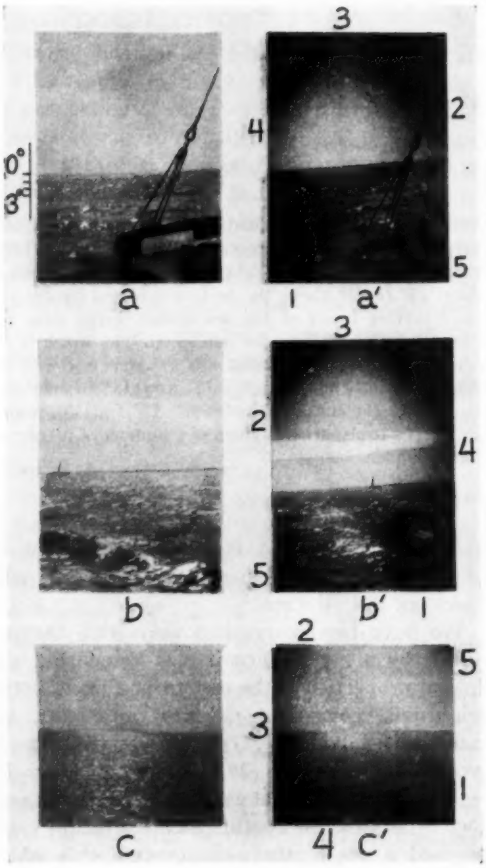

FIG. 1. a, b, c, unpolarized and a′, b′, c′, polarized photographs of sun path. a, a′, Atlantic Ocean, altitude of sun 48°, bright blue scene, breeze 12 knots, sea smooth; b, b′, Chesapeake Bay, altitude of sun 39°, bright blue scene, breeze 18 knots, bay choppy; c, c′, Long Island Sound, altitude of sun 26°, hazy, blue gray scene, breeze 6 knots, sound smooth.

a Nicol prism set always to eliminate the horizontal electric vector of the light darkened the sea relative to the sky and reduced the brightness of the sun path. It, thus, in general, made the horizon more distinct, diminished the glare of the sun path and therefore improved the ease of making an accurate sextant observation.

In Fig. 1 are photographs of the sea-sky scene underneath the sun with and without a Nicol prism over the camera lens. Pictures a, b and c, taken without the Nicol, are ordinary photographs; in pictures a′, b′ and c′, taken with the Nicol set to extinguish the horizontal electric vector, the region 1234 is the polarized portion. The region 125 is unpolarized and should be disregarded, being outside of the diagonal median plane of the Nicol. The pictures show the reduction in the intensity of the sun path, the darkening of the sea relative to the sky and the hardening of the horizon.

The Nicol prism was mounted in the eye-piece of the sextant telescope, being set always to extinguish the horizontal electric vector, and the improvement it gave was so marked that I never wished to do without it. Color filters were of course used to reduce the brightness of the sun, but with the Nicol horizon filters were found unnecessary. In the best cases the horizon, seen through the Nicol, underneath the sun appeared as a sharp deep blue edge of the sea, just as it appears at right angles to or away from the sun in clear breezy weather. For a fairly calm sea there was practically no sun path and the horizon was sometimes difficult to distinguish. The Nicol usually darkened the sea to some extent even in this case, and rendered the horizon more distinct. In hazy weather the Nicol cannot be said to reveal the horizon when the true horizon, without the Nicol, is completely obscured by haze. Theory indicated, and measurements accurate to 1 minute of arc showed, that the Nicol introduced no changes in the corrections to the altitude of the sun for height of eye, refraction, diameter of the solar disk, etc., as calculated from the usual formulas or tables.

The diminution in the brightness of the sun path occasioned by the Nicol increased with α, the altitude of the sun above the horizon. This is shown in Fig. 2 in which the ordinate γ is the amount by which the intensity of the sun-path sparkles was reduced by the Nicol compared to the attenuation of unpolarized light. The dots are measurements made with the polarization photometer, see Section IV, of the sun path near the horizon for breezy days at sea in sunny weather; the curve is a theoretical curve calculated from Fresnel's equations as described in Section V. In view of the fact that the measurements were difficult to make, the observed points agree as well as can be expected with the theoretical curve. In this case the theory is so simple and direct that we may without question

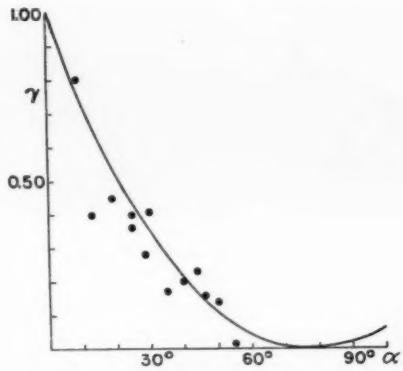

FIG. 2. Polarization of sun path; curve, theoretical, and dots, experimental.

accept the theoretical curve as being correct. The curve falls to zero at $\alpha = 72°$, which means that the Nicol reduced the sun-path sparkles to zero at this altitude of the sun. It is seen that the attenuation of the sun path was not great for solar altitudes below 20° but increased rapidly as α increased from 20° to 90°. Pictures a′, b′ and c′, Fig. 1, show the polarization effects down the sun path for $\alpha = 48°$, 39° and 26°, respectively.

III. The Polarizing Binoculars

The polarizing binoculars, shown in Fig. 3, were made by the Bausch and Lomb Optical Company and consisted of a standard pair of 6 power, 30 mm objective, binoculars with small Nicol prisms, of the Glan-Thompson type, fitted in tubes which screwed to the eye-pieces. The prisms could be rotated about their axes for best adjustment. The prisms reduced the intensity of unpolarized light by 50 percent and restricted to about 5° the field of view of the binoculars which without the prisms was 8°.

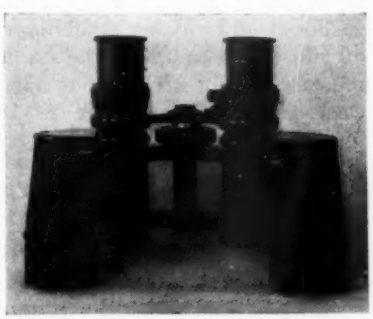

FIG. 3. Polarizing binoculars.

It was found that the polarizing binoculars often gave better seeing than ordinary binoculars. The light of the surface of the sea is always considerably polarized, the electric vector being mainly in the horizontal plane, whereas light from objects such as ships, sails, buoys, white caps, etc., is practically unpolarized. Therefore, setting the Nicol prisms to refuse transmission to the horizontal electric vector darkened the sea relative to the object and improved the contrast, and hence the visibility, of the object against the background. The polarizing binoculars gave the best improvement on bright days because on bright days (1) the polarization of the sea and sky was greater than on dull or overcast days, (2) the 50 percent loss of light due to the Nicols was less harmful than on dull days, (3) objects were more often brighter than the background than on dull days.

White lighthouses, white sails of ships hull down, white markings as the hatches of a motor boat, sea gulls, etc., at a distance as to be barely distinguishable with ordinary binoculars were easily seen with the polarizing binoculars. On several occasions the color of a ship, boat, buoy, etc., could not be made out with ordinary binoculars; with the polarizing binoculars its correct color was revealed immediately. The reduction of the sun-path glare produced by the Nicol prisms often enabled one to search the sea toward the sun effectively and with little fatigue.

In the case of haze so thick that the visibility was reduced below 4 or 5 miles, the polarization of the haze was practically zero and the Nicol prism offered no benefit in seeing through the haze. In the case of thin hazes which made objects, say 8 miles away, slightly bluish, the Nicol removed the blue veil slightly, so slightly, however, as to be inconsequential.

Continual tests with color filters added to the polarizing binoculars showed that the polarization effects were constant throughout the visible spectrum. This agrees with theory, Section V, which indicates no marked dispersion of the polarization.

In general, the light from most objects is polarized to some extent. A sandy beach seen

from a mile or more off shore was usually made relatively brighter by the Nicol prism, its true yellow color, or whatever color it was, being brought out slightly more clearly. The green color of trees or fields was heightened and made slightly greener. The light from an object is of two kinds: (1) some of the light is scattered from the object after partial penetration; this light gives the true body color of an object, such as the red color of a brick, or the green of a leaf; (2) some of the light is genuinely reflected from the surface of the object, giving the object a sheen or a sparkle. The first sort of light is unpolarized, the second partially or completely polarized; the first sort passes through a Nicol prism undisturbed, the second sort is partially or totally eliminated by the Nicol. Thus the Nicol serves to remove the *sheen* or the *glint* or the *sparkle* from objects and therefore to reveal their true body colors. The aspect of wet rocks, wet seaweed, a wet road, glare from paper, a granite boulder, a tobacco field in the sun, high lights on a painted surface, not, however, reflections from metals, are often completely changed when viewed through a Nicol prism.

However, although the polarization of trees, beaches, etc., was often quite marked, I did not find that the polarizing binoculars enabled me to make out details of objects on a distant shore much better than ordinary binoculars.

IV. Observational Data

A mixture of unpolarized and plane polarized light is completely described by γ and φ, where γ is the ratio of the intensity of the light, viewed through a Nicol prism, when the prism is oriented for maximum darkening of the light to the intensity at the orientation of minimum darkening; the two orientations are at right angles to each other. φ gives the direction of the electric vector of maximum polarization and in the case of the light of the sea or sky is the angle the vector makes with the horizontal plane. For $\gamma=0$ and 1 the light is completely polarized and unpolarized, respectively. The fraction of the total light which is polarized is given by $(1-\gamma)/(1+\gamma)$; although this expression is often referred to in experiments with polarized light we shall have no occasion to use it.

Fig. 4. Polarization photometer.

γ and φ were measured by means of the polarization photometer shown in Fig. 4. It consisted of a small telescope of 5° field of view with two Nicol prisms placed side by side in the eye-piece, the planes of transmission of the prisms being perpendicular. A gray optical wedge slid in front of one of the Nicols. The optical transmission of the wedge varied from 1.00 at its thin end to 0.01 at the thick end; the values of the transmission, which were also the values of γ, were marked on a scale along the wedge. The wedge was made of colloidal carbon in gelatin cemented between glass plates with balsam. The photometer was pointed at the scene and was rotated slowly about a longitudinal axis until the brightness of the field seen through one Nicol was a maximum and the other a minimum. In this position the orientation of the photometer with respect to the horizontal plane gave φ. The wedge was then slid along until it diminished the bright field of the first Nicol to equal that of the second Nicol. At this setting the transmission of the wedge was γ.

Referring always to a breezy sea and to the rim of the sea within 3° of the horizon, the polarization of the light of the sea depended on the polarization of the sky light, as might be expected. For cloudy weather at all hours of the day $\varphi=0$ and $\gamma=0.4$ to 0.2 for the sea, the sky being unpolarized. For a clear, but not abnormally clear, sky and atmosphere $\varphi<10°$ and $\gamma<0.2$ during the mid-day hours. As the sun neared the horizon γ and φ acquired values depending on the altitude and bearing of the sun. In general, at any bearing from the sun γ and φ were less for the sea than for the sky on that bearing, i.e., the light of the sea was always more strongly polarized and with electric vector more nearly horizontal than in the case of the

TABLE I. *Altitude of sun 45°.*

Bearing from sun	0°		30°		60°		90°		120°		150°		180°	
	γ	φ	γ	φ	γ	φ	γ	φ	γ	φ	γ	φ	γ	φ
sea	0.2	0°	0.3	15°	0.2	25°	0.1	30°	0.2	20°	0.2	10°	0.3	0°
sky α														
0°	0.8	0°	0.6	27°	0.4	40°	0.4	45°	0.5	41°	0.5	27°	0.6	0°
30°	1.0	0°	0.7	47°	0.4	54°	0.2	49°	0.2	38°	0.3	22°	0.3	0°
60°	1.0	0°	0.8	117°	0.5	85°	0.2	63°	0.2	43°	0 2	23°	0.2	0°

sky, the sea vector being tilted up from the horizontal in the same sense as the sky vector. In Table I are given values of γ and φ at various bearings from the sun and altitudes α in the sky for clear weather and the sun 45° above the horizon. The table is an average of a number of observations made on days of clear weather and a cloudless sky. Since it is known[1] that in the sky the direction of the electric vector of maximum polarization is in circles around the sun, the values of φ for the sky in Table I were calculated; the measurements agreed with them within the error of observation. The values of γ and φ at other solar altitudes are too numerous to give here, but in Section V is given the rule for finding them.

The ratio R of the brightness of the rim of the breezy sea to the brightness of the sky near the horizon is the reflectivity of the sea. For a clear atmosphere and sky R was 0.25 and did not vary much with the bearing and altitude of the sun. The same value of R held approximately for a uniformly cloudy sky. The brightness of the sky was constant within 20 percent for altitudes from 0° to 30° above the horizon for a clear or cloudy sky. These measurements were made with a small photometer.

V. THEORY OF THE SEA REFLECTION

Let the intensities of the components of the incident light, in this case the light of the sky or the sun, polarized with electric vector in the horizontal and vertical planes be unit vectors. Denote by ρ_1 and ρ_2, respectively, the intensities of the light reflected from the surface of the sea polarized with electric vector in the horizontal and vertical planes. ρ_1 and ρ_2 are given by Fresnel's equations

$$\rho_1 = [-\sin(i-r)/\sin(i+r)]^2, \quad (1)$$

$$\rho_2 = [-\tan(i-r)/\tan(i+r)]^2, \quad (2)$$

where i is the angle of incidence and r is the angle of refraction. i and r are related by the Snell equation

$$\sin i = \mu \sin r, \quad (3)$$

where μ is the refractive index of sea water.

For pure water for wave-lengths 4416, 5338 and 6560 Angstroms, μ is 1.3398, 1.3350 and 1.3310, respectively. With the average value $\mu = 1.335$, which refers well enough to sea water, the values of ρ_1 and ρ_2 for i from 0° to 90° were calculated from (1), (2) and (3); they are given in columns 2 and 3 of Table II.

TABLE II.

1 i	2 ρ_1	3 ρ_2	4 R	5 φ	6 γ	7 α
0°	0.020	0.020	0.020	—	—	180°
10°	.021	.020	.020	—	—	160°
20°	.025	.017	.021	—	—	140°
30°	.031	.013	.022	—	—	120°
40°	.044	.005	.024	—	0.11	100°
50°	.067	.000	.034	—	.00	80°
60°	.116	.004	.060	11°	.04	60°
70°	.223	.048	.135	25°	.21	40°
75°	.32	.11	.22	30°	.35	30°
80°	.46	.24	.35	35°	.52	20°
85°	.68	.49	.58	40°	.73	10°
90°	1.00	1.00	1.00	45°	1.00	0°

ρ_2 becomes zero at the Brewster angle $i' = \tan \mu$. For $\mu = 1.335$ $i' = 53°\ 10'$, and i' changes only by about 10′ as the wave-length of the light changes from blue to red. Therefore the polarization effects of the light reflected from sea water are constant to a first and close approximation with the wave-length, or color, of the light. This agrees with observation.

ρ_1 and ρ_2 are of course the reflecting powers of sea water for the two modes of polarization. The reflectivity of sea water for unpolarized light is

$$R = (\rho_1 + \rho_2)/2. \quad (4)$$

The values of R are in column 4, Table II.

For the light of the sky polarized at 45° to the horizontal plane the angle φ which the electric vector of the light reflected from the sea makes with the horizontal plane is given by

$$\tan \varphi = (\rho_2/\rho_1)^{\frac{1}{2}}. \quad (5)$$

The values of φ to the nearest degree are in column 5, Table II.

If the light falling on the sea is unpolarized γ for the light reflected from the sea is

$$\gamma = \rho_2/\rho_1. \quad (6)$$

The values of γ are in column 6, Table II.

Polarization of the sun path

The sun-path sparkles are images of the sun reflected by the facets of the water surface which are tilted toward the observer at an angle δ to the horizontal where

$$\delta = \alpha/2, \quad (7)$$

α being the altitude of the sun. Then $i = 90° - \delta$ and

$$\alpha = 2(90° - i). \quad (8)$$

The values of α from (8) are in column 7, Table II. Since the light of the sun is unpolarized, the values of γ of the sun path are those in column 5, Table II. The α, γ curve is plotted in Fig. 2. The comparison of the curve with the observations has been discussed in Section II.

The light of the sea comes mainly from the region of the sky at an altitude of 25° to 35°

The light of any area of the rim of the breezy sea seen by an observer is the light of the sky reflected to the observer by facets of the surface of the sea, but what part of the sky the light comes from has not been known. In the first place, the sea light comes largely from the region of the sky in the vertical plane passing through the observer and the sea area in question; in other words, the sea area does not reflect to the observer light from the sky off to one side. To prove this we need only quote the fact that the sun path is less than 30° wide for the sun below 50° in altitude (see Fig. 5). In the second place, the light comes mainly from the sky at 25° to 35° above the horizon. To prove this we consider two cases.

Case 1. Suppose that the light of the sky above the horizon is plane polarized with electric vector at 45° to the horizontal, which occurs approximately along the meridian at 90° to the sun for the sun at an altitude of 45° and a clear sky, as shown in Table I. Under these conditions, φ for the light of the sea at 90° to the bearing of the sun was observed to be about 30° (see Table I). From Table II we find that for $\varphi = 30°$, $\alpha = 30°$. The conclusion is not the only one possible as far as this case is concerned, for the observed angle $\varphi = 30°$ could be produced in a variety of ways by the summation in proper amounts of the light from other regions of the

a b c d

FIG. 5. Sun path. $\alpha = 7°$, 13°, 20°, 30°, $w = 3°$, 7°, 14°, 18° and breeze 3, 10, 18, 18 knots for a, b, c, d, respectively.

sky than those around a 30° altitude. In such a summation the contributions from altitudes below 30° must be insignificant, for otherwise, as seen from φ of Table II, φ for the sea would be greater than 30°.

Case 2. Suppose that the light of the sky is unpolarized as in cloudy weather. For this case the reflectivity of the sea was 0.25. From Table II for $R=0.25$, $\alpha=30°$. Again, as in Case 1, one could account for $R=0.25$ by making a proper summation of the contributions from various regions of the sky. In such a summation the regions below 30° would have to contribute the lion's share because light from regions above 30° is very little reflected, as shown by the values of R in Table II.

Combining Case 1 and Case 2 it comes out that the only region of the sky which satisfies the two cases simultaneously is the region of α from about 25° to 35°. Therefore, *the light of the rim of the breezy sea comes mainly from the region of the sky 25° to 35° above the horizon,* and, hence, from (7), *the reflecting facets of the sea which are visible to the observer are tilted up on an average at about 15° from the horizontal.* Other facets exist, of course, which are tilted at angles less and greater than 15°, but the 15° angle, or thereabout, is the most frequent tilt which appears to the view of an observer looking very obliquely at the surface of the sea. It follows that the state of polarization of the light of the breezy sea can always be calculated approximately from that of the sky at an altitude of 30° by means of Fresnel's equations with $i=75°$. For example, with an unpolarized sky, as in cloudy weather, γ for the sea determined by this rule is 0.35 (see Table II), the observed value being from 0.2 to 0.4.

The argument and calculation just given has been reduced to simplest terms. A more rigorous calculation would require more detailed measurements of the light intensity at all azimuths of the Nicol at all points of the sky and sea for various altitudes of the sun and conditions of weather. The conclusion that the wave facets were tilted about 15° in moderate weather seemed reasonable as far as could be judged from the appearance of the wavelets. Stokes'[2] calculation of a maximum 30° slope for deep sea waves of permanent type probably applies only in part, or perhaps not at all, to convolutions of the water surface which run the entire gamut from gravitational waves to wind-blown wavelets and finally to ripples. According to Stokes if the slope were greater than 30° the wave was unstable and would white cap.

From the foregoing results we are led to an understanding of a number of very familiar phenomena, so familiar that I doubt whether they have ever been commented upon. A few may be mentioned. If the water is ruffled by a breeze and if one is near a shore on which there are green trees, he sees no trace of green reflected in the water, but the water is blue nearly to the shore. The reason is that the water is reflecting light from the sky at 30° which has come down over the tops of the trees. This is exactly similar to the desert mirage. If the bank of trees is high enough one will see a narrow green reflection close to the shore and upon investigation will find that a line drawn from the outer edge of the green reflection to the top of the trees makes an angle of about 30° to the horizontal.

Similarly one sees practically no reflection of a black or white ship in the water on a breezy day.

A dark bank of clouds rising up over the horizon does not darken the sea appreciably until it reaches an altitude above 25°.

The sea takes its color from the sky at 30° although it is, of course, darker than the sky. The sky at 30° is usually bluer than the sky near the horizon. Hence the sea is usually bluer than the horizon sky. This may account for one's (correct) impression of the great blueness of the sea, for one probably gets this impression by comparing the sea with the sky near the horizon.

The width of the sun path

In Fig. 5 are photographs of the sun path for various altitudes α of the sun; the data of these and also of Fig. 1, a, b and c are in Table III, w being the angular width of the sun path. The values of w are plotted against α as black dots in Fig. 6. It is seen that w increases with α. When the sun is directly overhead there is of course no sun path, the sparkles of light being equally distributed around the horizon. w increases with the strength of the breeze, or the roughness of the water surface, reaching a maximum value

[2] Stokes, Mathematical and Physical Papers **1**, 227 (1880).

when white caps begin to form; when white caps are very abundant the sun path is not sharply marked. The maximum value of w is less than 30° for $\alpha < 50°$.

TABLE III.

	α	w	Wind velocity (knots)	White caps
Fig. 5a	7°	3°	3	none
Fig. 5b	13	7	10	none
Fig. 5c	20	14	18	many
Fig. 1c	26	12	6	none
Fig. 5d	30	18	18	many
Fig. 1b	39	25	18	many
Fig. 1a	48	23	12	few

Each sparkle of light of the sun path is a reflection of the sun by a facet of water surface so oriented as to reflect the sunlight to the observer. For plane facets sloped at an angle δ to the horizontal, the width of the sun path is twice the maximum angle from the bearing of the sun at which the facet can reflect the sunbeam into the horizontal plane. This condition is given by

$$w = f(\alpha, \delta). \tag{9}$$

Neglecting the curvature of the earth, which is unimportant, the function f of (9) is easily written down from spherical trigonometry but is too long to give here; it is made up of six equations with parameters which may not readily be eliminated. From (9) the curves of Fig. 6 were determined; they give w as a function of α for the value of δ marked on each curve. Each curve returns to zero at $\alpha = 2\delta$, the curve becoming imaginary for larger values of α; the curves for $\delta = 10°$ to 30° are drawn to their ends, the other curves end off the page. For a given w and α the curves give the maximum δ possible for the facets. They show, in agreement with observation, that w increases with the roughness of the sea δ and with the altitude of the sun α, becoming zero, i.e., as wide as the

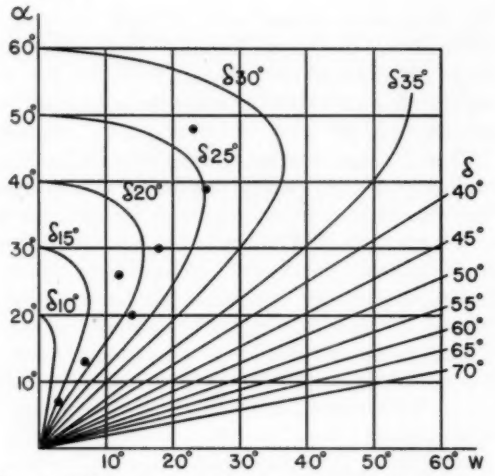

FIG. 6. Width of sun path; curves, theoretical, and dots, experimental.

sun, for $\alpha = 0$ for all values of δ. A comparison of the curves with the observed points shows that the maximum δ was less than 28° for an 18 knot breeze and less than 20° for a breeze of 10 knots and below. The result is in agreement with the 15° tilt determined from the polarization measurements.

If all the facets had the same δ the sun path would consist of two straight lines of sparkles stretching out from the observer at an angle w to each other, the bearing of the sun being half way between. If, as is actually the case, the region in between the two lines is filled with sparkles, there must be facets of a less δ than the δ for the edge of the path, with a distribution of δ such as to give the observed sun path. Thus observations of the distribution of light across the sun path for various altitudes of the sun would yield the distribution of δ among the sea facets, and hence, with sufficient mathematical ingenuity, the profile of the wavelets of the sea. This may be regarded as a difficult way to find out the shape of the wavelets.

The Influence of Certain Photographic Errors on the Profiles of Absorption Lines in Stellar Spectra

C. T. ELVEY AND CHRISTINE WESTGATE, *Yerkes Observatory*

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A study has been made of the Eberhard effect in its relation to the profiles of absorption lines. Measurements have been made of the depression of the background at the edge of an image, due to the inhibiting action of the products of development, for: (a) various differences between the density of the image and that of the background; (b) constant ratio of exposure of image to exposure of background, but different total densities; (c) varying time of development; (d) agitation during development; and (e) type of developer. The influence of scattered light from the back of the plate and the influence of the graininess of the emulsion have also been studied. The conclusion is reached that for Eastman 40 plates developed in D-11 at 70°F, and with a density of the continuous spectrum less than unity, the Eberhard effect and the halation from the back of the plate have a negligible influence on the profile of an absorption line. The profiles of artificial absorption lines are shown.

I.

IN the course of the investigations at the Yerkes Observatory on the profiles and the total absorptions of lines in stellar spectra, a number of questions have arisen concerning the magnitudes of certain errors which enter into the photographic processes. In a large part of our spectrophotometric work we use the unbacked Eastman 40 plate, develop it in D-11 at a temperature of about 70°F, and during development rock the tray by hand, keeping the developer well agitated. Under these conditions what is the influence of the Eberhard effect upon the profile of a spectral line? How do other effects, which may not be dependent upon the development procedure, such as scattered light in the instrument, halation in the plate, and the graininess of the emulsion, act upon the shape of a spectral line?

There is some evidence that our measurements of the total absorptions of lines depend upon the density of the spectrogram. We have checked this by taking a series of five spectrograms of the star γ Orionis with the single-prism Bruce spectrograph attached to the 40-inch telescope and by determining the profile of the Hδ line in the usual manner. The densities of the continuous spectrum at Hδ range from 0.1 to 1.6 on these spectrograms. Four of the spectrograms of densities 0.9 and less gave sufficiently consistent results, the largest deviation from the mean being 13 percent. Errors of this size for wide hydrogen lines may be introduced by variations in the judgment of the measurer in sketching the continuous spectrum across the absorption line.[1] The spectrogram of highest density (1.6) gave a total absorption of less than 50 percent of the mean of the other four. This, we believe, was caused by reflection of light from the back of the plate. A discussion of this effect follows in a later section.

II.

In most of the experiments a sharp-edged image was required. For this purpose the shadow of a razor blade, cast by a distant light was used. The exposures were made in a specially constructed plateholder containing an aluminum plate having two apertures about 1½ mm wide and 75 mm long. Across one opening a double-edged safety razor blade was mounted with adjustments by which it could be made concave toward the emulsion and brought almost in contact with it. The adjustment was such that no light could be reflected from the emulsion into the shadow cast by the blade. The plates were the same as those employed in the regular work of the Bruce spectrograph and were calibrated with a tube sensitometer of 14 holes in two rows having a range in relative intensity of

[1] Astrophys. J. **72**, 277 (1930).

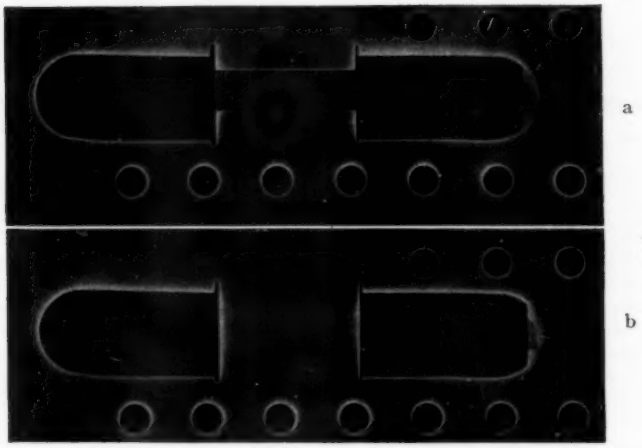

FIG. 1. Plates showing the effect of "flashing" on the chemical fog and on the depression of density at the edge of an image.

about five magnitudes. The plate was exposed behind the blade to a flashlight bulb of low luminosity at a distance of five meters, and was then placed behind the other aperture and was given a short exposure in order to flash the region in the shadow of the razor blade. The exposed area lay between the two rows of sensitometric spots. In the experiment on halation the flashing was done to increase the threshold sensitivity of the emulsion, while in the experiment for the Eberhard effect the purpose of the flashing was to give a background density from which to measure the depression near an image.

III.

In discussing the Eberhard effect we must distinguish between its various manifestations. First, there is the building up of density around the edge of a dense image, due to the diffusion of fresh developer into the region of development. This has been discussed by the discoverer, G. Eberhard,[2] by N. Walenkov[3] and by many others. Our investigation is not particularly concerned with this phase of the effect but with its complement, the diffusion of the reaction products of development into the regions of shorter exposure and consequently the retardation of complete development in the immediate vicinity of a strongly exposed image.[4] This phenomenon may be divided into two classes: the depression in the background of the chemical fog near an image and the depression in an adjoining exposed area. It is the depression in the chemical fog near images that is noticed by visual examination of plates; this is not a measure of the distortions one would expect on the profiles and intensities of absorption lines. We can illustrate the difference by Fig. 1, which is a reproduction of two of our plates on which only a strip across the shadow of the razor blade was flashed. On both plates the densest exposure is the same. For (a) the flashed exposure was six seconds and for (b) two seconds. The plates were developed for a sufficient length of time to give a rather heavy chemical fog. An examination of the plates shows that there is a large depression in the chemical fog at the edges of dense areas, but in the region where the flashing has given a density of about the same order of magnitude as the chemical fog (a) there is a very small depression. For the other plate the flashed area had an exposure about one-third as long, and the density is definitely below that of the chemical fog. The flashing of the plate inhibits the chemical fog. This is shown also in the fainter sensitometer

[2] G. Eberhard, Phys. Zeits. **13**, 288 (1912).

[3] N. Walenkov, Zeits. f. Wiss. Photographie **27**, 236 (1929).

[4] Zeits. f. Physik **80**, 506 (1933).

spots—an effect discovered by F. E. Ross.[5] The phenomenon is shown in the microphotometer tracings in Fig. 2, made across the edges of the

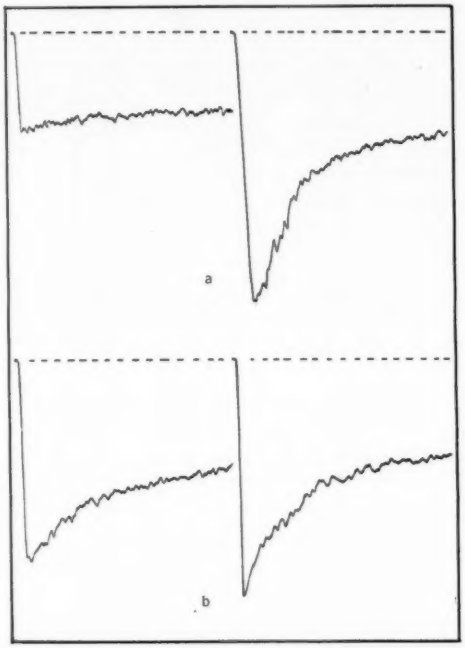

FIG. 2. Microphotograms of images shown in Fig. 1, (a) and (b). Those on the left are for regions that have been flashed and those on the right are for unflashed regions.

shadow of the razor blade in Fig. 1. The two upper curves are tracings of (a) and show the difference between the flashed (left) and the unflashed regions. The lower curves are for (b), in which the flashing was of much shorter duration. Here the difference is not so pronounced. In practically all cases in stellar spectroscopy the residual intensity within an absorption line is sufficient to give an effect of flashing equivalent to that shown in Fig. 1a, and consequently the Eberhard effect with which we are dealing is a totally different phenomenon from that which one sees visually on a plate. In all of our work we have flashed the plates to eliminate this effect and also to give a density from which to measure. The region of the sensitometric spots was not flashed.

[5] F. E. Ross, Astrophys. J. 73, 54 (1931).

In our first series of experiments we studied the variation of Eberhard effect with density on backed Eastman 40 plates, developed in D-11 at a temperature of 70°F. The exposures were as follows: 150:6, 90:6, 60:6, 30:6, and 15:6, the first figure giving the total exposure of the image in seconds and the second giving the exposure of the flashed area. For each exposure time three plates were taken, one being stationary during development, another rocked and the third brushed. The three trays of developer were poured from the same bottle, which had been kept at the required temperature. The plates have been measured with the registering microphotometer and the results are shown in Fig. 3, upper section. The ordinates, expressed in stellar magnitudes, give the depression of the background near the image and the abscissae are distances from the edge of the image in millimeters. The effect is greatest at the edge of the image and decreases to zero at a distance of 0.5 mm for the most pronounced case. In the upper row are the results from stationary development; in the second, those obtained from plates which had been rocked. The lower illustration gives the results for plates which had been brushed. Decreasing exposures are plotted toward the right in the order listed above. The densities of the rocked plates for the above exposures are: 1.6, 1.2, 1.1, 0.7 and 0.3. The depression of the background exposure near an image is of course largest for the stationary plates and also increases with the density of the image. The rocked and brushed plates show a marked improvement over the stationary ones. For densities of the image up to 0.7 on rocked or brushed plates we found no effect, but for densities of 1.1 and greater the depression is of importance. In all of these cases, however, we have the maximum effect since we have a very sharp-edged image. In practice, all spectral absorption lines have a considerable edge gradient. Furthermore, the difference in the amount of light falling on the dense area and on the background is much greater than that between the center of the line and the continuous spectrum of most absorption lines in stellar spectra.

An anomalous result was found in the case of the exposure of 60:6, density 1.1, in that the effect was very large both for the stationary and

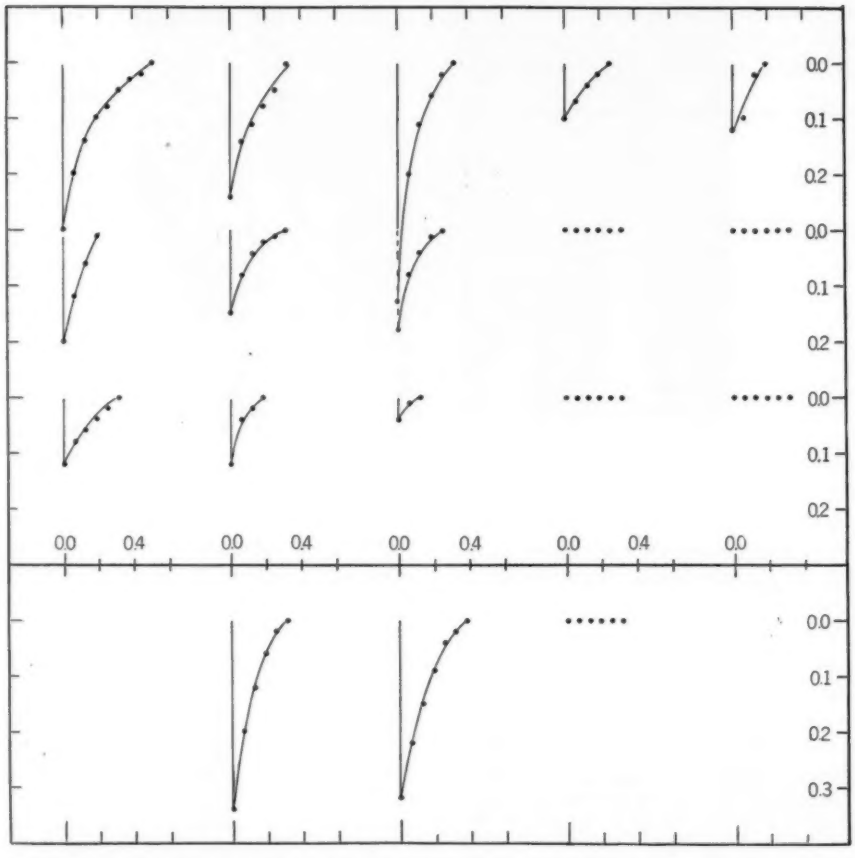

FIG. 3. The depression of the background at the edge of an image, caused by the Eberhard effect. The abscissae are millimeters from the edge of the image and the ordinates are the depressions in the background density calibrated in terms of the difference in light intensity (magnitudes) that would have been necessary to produce them.

for the rocked plates. We repeated the experiment for this exposure and for that of next higher density and obtained the same results even though we had another emulsion and a new solution of developer.

A series of experiments was made covering the same range of total exposures as above but always keeping the same ratio, 2.5 to 1, between the exposures for the image and those for the fog background. The exposures are as follows: 15:6, 30:12, 60:24 and 120:48. This ratio of exposures should give a difference in density roughly equal to that found between the continuous spectrum and the center of an absorption line having a depth of 60 percent. For each exposure time a pair of plates was obtained, one being developed while in a stationary position and the other while rocked. The microphotometric tracings show no depression of the background at the edge of the image for the rocked plates, and for the stationary ones the effect is no larger than that shown in Fig. 3 for the same exposure ratio, 15:6. This shows that even in the severest case a line with abrupt edges, having a central depth of 60 percent can be kept practically free from the influence of the Eberhard effect by proper development.

The effect of time of development is shown in the lower part of Fig. 3. For this experiment we took three plates with the same exposure times,

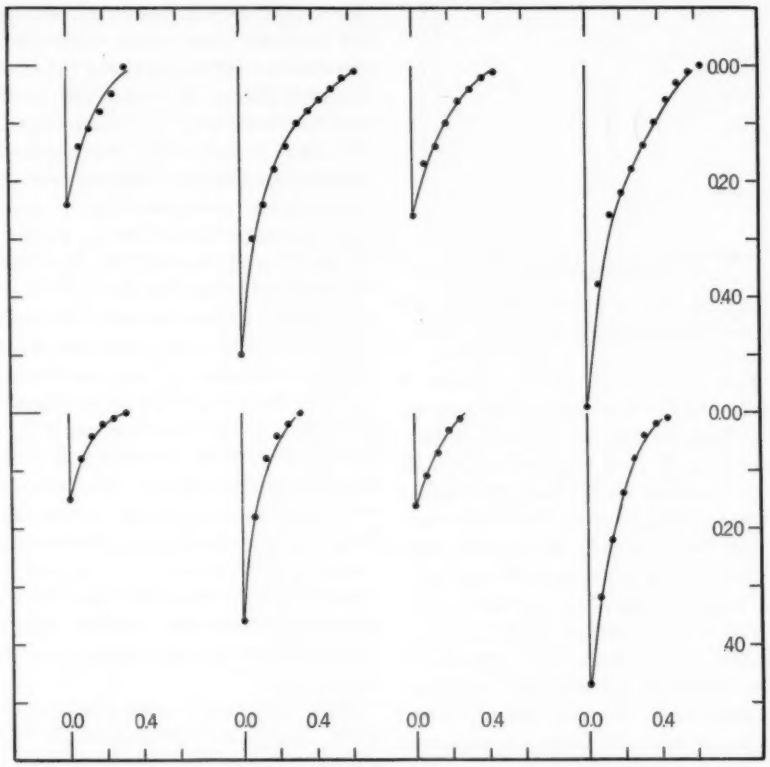

FIG. 4. The depression of the background at the edges of images developed in various developers.

90:6, and developed them in stationary trays for 3, 6 and 12 minutes. The densities are, respectively, 0.7, 1.1 and 1.6. There was no effect discernible for the shortest time of development, but the two other plates gave about equal effects.

We tested several of the other developers used at the Yerkes Observatory for various kinds of work, and the results are shown in Fig. 4. In the upper row are the results from stationary development, and in the lower from rocked development. From right to left we have D-11, D-61a, Rodinal and Nepera, the last, however, without the auxiliary powders recommended for the solution when used for the development of plates. This test is not quite fair to all of the developers, since the time and the temperature were those which we ordinarily use for D-11, that is, five minutes at 70°F. The exposures in all of the above tests were 90:6. The differences are large enough to show definitely that D-11 and Rodinal give less trouble from Eberhard effect than the other two developers.

IV.

The trial exposures made in the study of the Eberhard effect were on unbacked plates and it was found that in the stronger exposures light was reflected from the back of the plate into the region corresponding to the shadow of the knife-edge. It was strongest at the knife-edge and decreased inward into the shadow. A microphotometric tracing of a typical plate, made with an exposure of 100:4, is shown in Fig. 5. The distance between the vertical lines on the tracing corresponds to 21.5 mm on the plate. One can readily see that in the case of a strongly exposed plate an absorption line would be "filled in" by the reflected light from the back of the plate. A series of exposures was made in order to de-

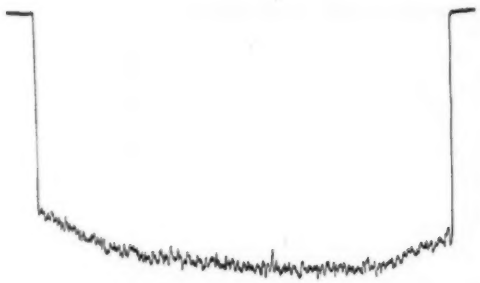

FIG. 5. Microphotogram showing the scattered light at the edge of an image photographed on an unbacked plate.

termine the effect of halation on the profiles of absorption lines in stellar spectra. The exposures, with unbacked plates, were as follows: 100:4, 60:4, 40:4, 20:4, 10:4, 20:8, 40:16 and 60:24. The plates were Eastman 40 and were developed in D-11 at a temperature of 67°–70°F for five minutes. During development the plates were rocked thoroughly in order to reduce the Eberhard effect to a minimum. Tracings of all the plates were made with the microphotometer. The first exposure showed the effect of halation strongly but its influence in the second exposure is somewhat uncertain. For exposures of 40 seconds or less the effect is definitely absent. The last plate, for which the exposure for density of the image was 60 seconds and the fog exposure 24 seconds, shows no evidence of halation on our microphotometric tracings. The density of the exposure corresponding to 40 seconds is 1.1. This is about the upper limit for which accurate photometric work can be done with most recording microphotometers, hence we may conclude that halation from the unbacked plates is insufficient to distort the profiles of absorption lines for the average run of stellar spectrograms. In cases in which it is necessary to give exposures which produce densities greater than 1.1 the plate should be backed. We have made exposures on plates backed with Eastman "Opaque" which gave densities up to 2.0 and have found no difficulty from this source, although the Eberhard effect then becomes noticeable.

V.

To test the scattering of light near the edges of a sharp image formed on a spectrogram, the spectrograph was pointed toward the sky and an exposure was made with the slit partially covered for three-fourths of the exposure and uncovered during the remainder of the time. This was to simulate a very sharp-edged line of about 75 percent absorption. Three spectrograms were made with different total exposures and were run through the microphotometer at right angles to the spectrum. There was no measurable amount of scattered light from the edge of the spectrum. In order to make the test with the spectrograph operating under normal working conditions, spectra of Vega were obtained through the comparison windows of the spectrograph, the exposures being rather longer than normal. The densities of the two spectra were 2.0 and 1.0. The center of the plate containing the spectral exposures was flashed by means of a light in the dark-room, in order to increase the sensitivity. Runs across the exposed areas at different wave-lengths showed no measurable scattered light. The optical parts of the Bruce spectrograph had been previously cleaned and consequently there should be little difficulty from dust on the lenses.

This procedure measures the scattering at right angles to the dispersion and, of course, cannot be used as a criterion for the scattering of the light of the continuous spectrum into an absorption line, for there are some effects which are directional, such as coma, etc.

VI.

In order to test further the influence of photographic effects upon the determination of the profiles of spectral lines, we constructed an apparatus for making artificial lines. This consisted of a cylinder five inches in diameter and 14 inches long, in which a slot 2 cm by 20 cm was inserted along the length of the cylinder. This aperture was covered with a strip of flashed opal glass. On the inside of the cylinder opposite the slot was placed a row of ten flashlight bulbs in a series circuit. In a diametrical plane of the tube, perpendicular to the plane of the lights and the slot, was placed another flashed opal-glass diffusing screen. The inside of the apparatus was coated with white enamel. By enclosing the ends of the cylinder with

mirrors, uniform illumination of the narrow strip of opal glass was made possible; this could be used as a source to represent a continuous spectrum. Tests made by photographing the source on a scale reduced to 1/15, on Process plates which were then developed to high contrast, showed that for our purposes the illumination along the source was uniform. This tube was mounted inside a rotating cylinder 7 inches in diameter and 15 inches in length. A section was taken out of the wall of the rotating cylinder so that an aperture 20 cm by 20 cm was available, and this opening was covered with two sheets of Kodaloid. A mask of any desired shape cut from black paper could be inserted between the two sheets of Kodaloid. A photograph of the light source while the cylinder is rotating integrates along the direction of rotation, and the shape of the mask determines the effective intensity from the different parts of the uniformly illuminated strip.

We used one of the spectrograph cameras, set up at a distance of five meters and focussed accurately on the mask. This gave an image of the source 1.2 mm by 13 mm. The first mask was one which would produce an artificial line in which the effective exposure for the center of the line was 25 percent, with one of its edges jumping abruptly back to 100 percent intensity and the other edge sloping gradually back along a straight line. Several exposures were taken with this mask and a profile, obtained from an average of the results, is shown in Fig. 6. The shortest exposure is that obtained from 100 turns of the rotating cylinder. In this diagram the ordinates are percentages of absorption and the abscissae are millimeters. The measures across the width of the line have been reduced to the original size of the mask. The profile of the line has been drawn in from the relative size of the mask and the aperture. The exposures were all made on backed Eastman 40 plates developed in D-11 for five minutes at 70°F with thorough rocking. The influence of the Eberhard effect and of the scattering of light from the back of the plate is seen to be negligible. The lack of sharpness at the abrupt edge of the line is due to lack of resolving power in the equipment, but this is small in comparison with the effects which are here sought.

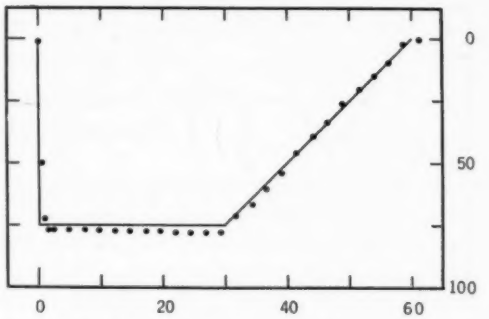

FIG. 6. Profile of an artificial absorption line as described in the text. The ordinates are percentages of absorption.

Another mask was made having two triangular-shaped lines with depths of 75 percent for the wider one and 50 percent for the other. The widths of the two lines on the photograph are 2.8 mm and 0.7 mm, respectively, corresponding to lines of 28A and 7A width at λ4500 in the three-prism Bruce spectrograph. Again Eastman 40 backed plates were used with the usual development. A series of four plates of exposures of 100, 200, 300 and 600 seconds was obtained to note any effect of density upon the results. Fig. 7 shows the reduced profiles, the ordinates being percentages of absorption and the abscissae millimeters on the original mask. The curves are plotted in the order of decreasing densities of the images, which are, respectively, 1.5, 0.95, 0.85 and 0.44. Essentially the same results were obtained from the plates of the various densities, excepting perhaps the one of lowest density, for which the central intensity of the line seems to be somewhat less. This, however, may be a result of the waviness observed in some of the profiles, which was found to be of instrumental origin.

VII.

The graininess of an emulsion is a measure of the distribution of the individual grains rather than a measure of their size. C. E. K. Mees[6] has shown microphotometric tracings from various emulsions uniformly blackened to a density of 0.3 which exhibit the relative structure or graininess very nicely. The irregular distribution of the grains blurs out the fine details and calls

[6] C. E. K. Mees, J. Opt. Soc. Am. **21**, 762 (1931).

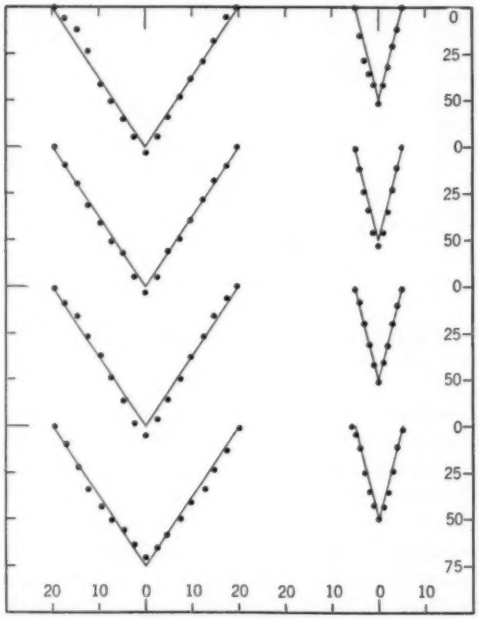

FIG. 7. Profiles of artificial absorption lines.

for considerable judgment in determining what is real. An inexperienced person is apt to put too much emphasis on the deviations of the tracing and as a result sees too many faint lines or too much detail in the more intense lines. Fig. 8 shows microphotometric tracings of two equally dense spectrograms of 53 κ Orionis. The upper is from a fine-grain Process emulsion and the lower is from a Par-speed emulsion. On the tracing from the Par-speed emulsion the Mg II line λ4481 is practically obliterated by the graininess. At best there would be a large percentage error in the determination of its total absorption. For

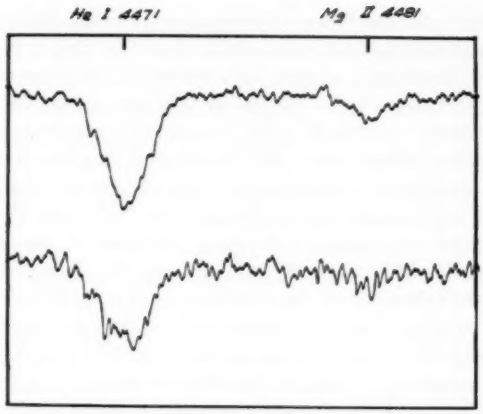

FIG. 8. Microphotograms of spectra of 53 κ Orionis in the region of the absorption lines He I 4471 and Mg II 4481. The upper is from a Process plate and the lower from a Par-speed plate.

the stronger line of He I the error would not be so great, nevertheless there would be considerable uncertainty in sketching the continuous background and the smooth curve for the line itself.

SUMMARY

We may summarize our results as follows: for Eastman 40 plates developed in D-11 at 70°F for five minutes there is no appreciable influence of the Eberhard effect on the profile of an absorption line as long as the density of the continuous spectrum is less than unity. Likewise, it is found that the halation from the back of the plate is not serious under these conditions.

We wish to express our gratitude to our colleague, Professor Ross, for his helpful suggestions.

Proceedings of the Eighteenth Annual Meeting of the Optical Society of America

BUCK HILL FALLS, PENNSYLVANIA
October 19–21, 1933

THE eighteenth annual meeting of the Optical Society of America was held at Buck Hill Falls, Pennsylvania, October 19 to 21, 1933.

The meeting was opened Thursday, October 19, at 9:30 A.M. by Vice-President Rayton.

PUBLIC LECTURE ON "A HUNDRED YEARS OF PHOTOGRAPHY"

On Thursday evening, October 19, Dr. C. E. K. Mees of the Eastman Kodak Company gave by invitation a lecture on the history of photography, tracing its development from the bitumen process of Niepce and the silver iodide and mercury process of Daguerre down to the modern dry plates and developing papers.

SESSION DEVOTED TO A CENTURY OF PHOTOGRAPHY

The sessions Friday morning and afternoon were devoted to papers on *"A Century of Photography."* The following papers were presented by invitation:

9:30 A.M.

The Development of the Photographic Objective, by Rudolph Kingslake, University of Rochester

The Reproduction of Tone Values, by L. A. Jones, Eastman Kodak Company

Photographic Photometry, by George R. Harrison, Massachusetts Institute of Technology

1:30 P.M.

The Photographic Reproduction of Sound, by Donald MacKenzie, Electrical Research Products, Inc.

The Color Sensitivity of Photographic Materials, by C. E. K. Mees, Eastman Kodak Company

Color Photography, by Burt H. Carroll, Bureau of Standards

DINNER IN HONOR OF PROFESSOR ROBERT WILLIAMS WOOD

The society's committee on award of the third Frederic Ives medal having awarded this medal to Professor Robert Williams Wood, the medal was presented to him by Dr. K. K. Darrow, Chairman of the Ives Medal Committee at a dinner held in honor of Professor Wood on Friday evening, October 20. Tributes of honor and respect were paid to Professor Wood in recognition of his distinguished work in optics.

BUSINESS SESSION

A brief business session of the Society was held Saturday morning, President Crittenden presiding. The Secretary and the Treasurer laid before the Society the formal reports for the calendar year 1932 (published in J. O. S. A., Vol. 23, No. 6, pp. 224–227, June, 1933) and gave informal statements of the changes which had taken place since January 1, 1933.

The President announced the usual joint meeting with the Physical Society in New York City in February, noting that the place of the 1934 annual meeting had not yet been decided.

At the close of the session the result of election of the officers and directors (see minutes of meeting of directors) was announced.

INVITED PAPERS ON THE PREPARATION AND PROPERTIES OF THIN METAL FILMS

On Saturday morning after the business session the following invited papers were presented:

The Optical Properties of Metal Films, by R. W. Wood, Johns Hopkins University

The Preparation and Properties of Sputtered Metal Films, by E. O. Hulburt, Naval Research Laboratory

The Preparation of Reflecting Surfaces for Various Spectral Regions, by John Wulff, Massachusetts Institute of Technology

Electron and X-Ray Diffraction Studies of Metallic Films, by G. A. Morton, Massachusetts Institute of Technology

ATTENDANCE

The attendance was as follows: Members 60, Guests 36, Total 96.

BOSTON UNIVERSITY
COLLEGE OF LIBERAL ARTS
LIBRARY

SESSIONS FOR THE READING AND DISCUSSION OF CONTRIBUTED PAPERS

Sessions for the reading and discussion of contributed papers were held as follows:

Thursday, October 19 at 9:30 A.M.
Thursday, October 19 at 1:30 P.M.
The authors' abstracts of these papers are appended.

MEETING OF THE BOARD OF DIRECTORS

Sessions of the Board of Directors were held as follows:

Thursday evening, October 19
Friday evening, October 20
Saturday morning, October 21

L. B. TUCKERMAN, *Secretary.*

Minutes of the Second Meeting of the Directors of the Optical Society of America, Incorporated

October 19, 20, and 21, 1933

Besides the transaction of routine business, the following items of general interest to members of the Society were taken up:

Announcements by Secretary

(a) By-laws adopted May 26, 1933, as announced in J.O.S.A. Vol. 23, No. 7, p. 26, July, 1933. The Proposed By-laws had been printed in J.O.S.A. Vol. 23, No. 4, pp. 151–155, April, 1933.

(b) Charles Bittinger appointed by President, representative of the Optical Society of America at the dedication of the George Eastman Research Laboratory of the Massachusetts Institute of Technology on May 1, 1933.

(c) Representatives of the Optical Society of America on the Division of Physical Sciences, National Research Council. Nominated by President and elected unanimously by letter ballot May 10, 1933.

Carl L. Bausch
L. B. Tuckerman (Executive Member)
D. L. Webster

(d) Unofficial tellers appointed by President to make unofficial count of ballots for election of officers and directors October 10, 1933.

Burt H. Carroll
W. J. Humphreys
James E. Ives

Financial Status of the Society

The Treasurer gave an informal report which showed that in spite of a materially greater loss of income than had been estimated in the budget the operating deficit at the end of 1933 would probably be less than $50.00 instead of $175.00 as estimated in the budget.

Budget for 1934 Adopted

A budget for 1934 was adopted providing a small surplus of estimated income over estimated disbursements.

Relations with American Institute of Physics

Discussion of the arrangements with the American Institute of Physics showed that the savings effected by the unification of publication of journals of physics under the auspices of the Institute had been very largely responsible for the favorable financial condition of the Optical Society. A new contract with the Institute to cover the publication of the journal during 1934 was discussed in detail, and approved in principle. Final action on the contract was deferred pending further study of its provisions.

Gift from Estate of Adolph Lomb

The Treasurer reported receipt of a check for $500.00 from the estate of Adolph Lomb "as a contribution to the Optical Society of America for the year 1933." The letter enclosing the check stated that this carried out the last wishes of Adolph Lomb. The disposition of this gift was considered at some length. It was finally voted that

"The Treasurer is instructed to hold for the present the $500.00 received from the estate of Adolph Lomb and the income from it in a special fund, and the Finance Committee is instructed to recommend to the Board of Directors the use to which this money shall be put."

Honorary Members Elected

By unanimous vote the Directors approved the election of Edward L. Bausch and Charles Fabry as honorary members.

Proxies of Optical Society

The President, Secretary, and Treasurer or any two of them were authorized to designate a proxy to represent the Optical Society of America at any meeting of the American Institute of Physics.

Transfer from Associate to Regular Membership

The following were transferred from associate to regular membership:

Walter Edward Albertson (642 A)
John G. Albright (726 A)
Paul L. Bayley (619 A)
Edward L. Bowles (450 A)
Barnett Cohen (690 A)
Arthur F. Dittmer (623 A)
Charles G. Ferrari (839 A)
A. P. M. Fleming (569 A)
John W. Forrest (900 A)
Carl E. Foss (878 A)
G. E. Grantham (774 A)
Frederick R. Hirsh, Jr. (747 A)
Donald Hubbard (615 A)
Serge A. Korff (823 A)
Overton Luhr (921 A)
David W. Mann (743 A)
J. Franklin Meyer (596 A)
Parry H. Moon (738 A)
Donald R. Morey (889 A)
Dorothy Nickerson (545 A)
Fred H. Perrin (406 A)
Orrin Weston Pineo (566 A)
Joseph Razek (704 A)
Murray R. Scott (939 A)
Francis W. Sears (919 A)
Leland B. Snoddy (859 A)
Joseph W. Tanch (671 A)
Mary Elizabeth Warga (893 A)
Julian H. Webb (941 A)

Report of Ives Medal Committee

The report of the Ives Medal Committee, awarding the medal to R. W. Wood, was accepted.

Physical Society of London

The President of the Optical Society of America has been elected an ex-officio fellow of the Physical Society of London.

The Directors voted:

"The Secretary is instructed to record the President of the Physical Society of London as an ex-officio member of the Optical Society of America."

Election of Officers

At its session Saturday morning, October 21, 1933, the Directors verified the count of the ballots made by the unofficial board of tellers. The following officers and directors were declared elected:

For President—W. B. Rayton
For Vice-President—A. C. Hardy

For a term of 2 years

For Secretary—L. B. Tuckerman
For Treasurer—H. F. Kurtz

For a term of 4 years

Directors

A. H. Compton
H. E. Ives — for a term of 4 years
C. W. Keuffel

R. C. Gibbs
G. B. Pegram — for a term of 2 years

L. B. TUCKERMAN, *Secretary.*

Program of Sessions for Contributed Papers*

(TITLES AND ABSTRACTS OF PAPERS)

1. A Reflection Densitometer. JOHN W. MCFARLANE, *Kodak Research Laboratories.* (15 minutes.)

A reflection densitometer designed primarily for research and product control on photographic printing papers is described in detail. It can be used also in connection with photo-mechanical halftone production work. Simplicity of design and relatively low cost of construction are combined with precision ample for all practical purposes. The paper concludes with a short description of factors influencing the measurement of reflection density.

The present paper will appear in full in J. Opt. Soc. Am. or Rev. Sci. Inst.

2. Photometric Applications of Scratched or Pattern Mirrors. RICHARD S. HUNTER, *Bureau of Standards.* (Introduced by E. C. Crittenden.) (15 minutes.)

It is a simple matter to scratch portions of the silvering from either ordinary commercial, or laboratory-deposited mirror. If a narrow razor blade is used, the edges in the scratched pattern may be made sharp enough to act as dividing lines in a photometer head. Gage has used this type of head for many years.[1]

Because of the low cost and ready availability of any size or pattern in such a photometer head, it should find wide application to the simple problems of brightness measurement and color comparison. The field obtained is most satisfactory when cut large enough to view directly without magnification. Such a photometer without a lens system provides the least confusing type of instrument for student study.

A large photometric field formed from two large brightly illuminated surfaces may be projected upon a screen and used to demonstrate photometric method. Thus, the need for a projected pattern in which one component may be varied independently of the other is satisfied. Some interesting possibilities in the use of motion, rather than quality difference, as a criterion for photometric balance are offered by a moving pattern mirror. The reflecting surface may be moved in its own plane.

The chief difficulty in the pattern mirror seems to lie in the selectivity of silvered surfaces.

Some instruments in which the pattern mirror is used will be shown.

[1] Gage, Trans. Ill. Eng. Soc. 19, 508, July (1924).

3. Preparation and Optical Properties of Evaporated Metal Wedge Films. BRIAN O'BRIEN AND T. A. RUSSELL, *Institute of Optics, Rochester, N. Y.* (15 minutes.)

Evaporated metal films of continuously varying density have been deposited on quartz plates by causing a beam of metal atoms to pass through a rotating sector disk with a profile cut in the form of an Archimedes spiral. The metals have been evaporated either directly from a tungsten filament or from a crucible at gas pressures below 10^{-4} mm of mercury with the source a sufficient distance from the quartz plate so that, in the absence of the sector disk, a uniform deposit results. The disk was rotated approximately 20 r.p.s. by a specially constructed polyphase motor with enamel and glass insulation only, the plane of the disk being parallel to and less than 2 mm from the surface of the quartz plate. With the disk at rest the metal deposit shows a sharply defined shadow of the spiral. By adjusting the evaporation rate so that several minutes are required to form a deposit, the total number of metal atoms striking any given zone on the plate is directly proportional to the distance of this zone from the origin of the wedge, regardless of slow variations in the rate of evaporation. Thus if the probability of an atom remaining on the plate is independent of the number of metal atoms per unit area already deposited, the wedges formed should be strictly linear.

Aluminum wedges measured at any one wave-length from 2200A to 6000A exhibit a uniform rate of change of optical density after the film has exceeded a certain critical thickness, indicating a linear deposit. Silver wedges show a linear change in optical density at any wave-length 2200A to 3000A and from 3400A to 3600A, but the rate of change of optical density shows wide departures from a linear law at wave-lengths greater than 3800A. Both first surface and quartz silver interface reflection densities fail to show the large departures from a linear law exhibited on transmission.

4. An Electrical Device for the Determination of Trilinear Coordinates for the Razek-Mulder Color Analyzer. JOSEPH RAZEK, *Randal Morgan Laboratory of Physics, University of Pennsylvania.* (15 minutes.)

The computation of trilinear coordinates involves three integrations of the form $\int_0^\infty R_\lambda D_\lambda E_\lambda d_\lambda$, where R_λ is the reflection or transmission factor of the sample, D_λ is respectively each of the three I.C.I. (C.I.E.) distribution curves, and E_λ is the energy distribution function of the selected illuminant.

The galvanometer current obtained in the Razek-Mulder color analyzer is proportional to the function R_λ. This small galvanometer current, at most a few microamperes, is amplified in a recently-developed d.c.-a.c. amplifier in which an alternating voltage of any reasonable magnitude proportional to the small direct current is

* The abstracts were preprinted in the program subject to correction by the authors. Corrections that have been communicated to the secretary have been made in the abstracts reprinted below.

obtained. This alternating voltage is impressed upon the potential coil of an induction type watt-hour meter. The gain in the last stage of the amplifier is made to vary in accordance with the desired distribution function D_λ, resulting in the application of a potential equal to the product of $R_\lambda D_\lambda$, to the watt-hour meter. The current through the current coil of the meter is made to vary proportionally to the energy distribution of the light source used, generally one of the I.C.I. (C.I.E.) illuminants.

The functions are made to vary together in the proper time relation by being determined by cams, driven through a reducing gear by a small governor-controlled induction motor. The number of revolutions of the meter disk during the cycle of operation will be proportional to the desired integral for the selected distribution function D_λ. Three systems are used, one for each of the distribution functions. Any number of illumination functions E_λ, can be built into the device and the desired one selected by electrical means.

The number of revolutions made by each watt-hour meter disk is determined by a photo-cell and amplifier system operating a magnetic counter through a relay.

Attention was paid to the elimination of phase shifts between the current and potential circuits of the meters and to the maintenance of linearity in the various amplifiers by using large capacity tubes and working these over small ranges.

Provision for the manual insertion of function R_λ will be made to allow the use of the device for the computation of data obtained by any spectrophotometer.

Bibliography:

Hardy and Perrin, *The Principles of Optics*, Chapter XIV.
Zworykin and Wilson, *Photocells and their Application*, 2nd Ed. p. 241.
Judd, Abstract No. 14. O. S. A. Feb. 1933, Meeting.

5. Comparison of Cobb's and Munsell Research Laboratory's Data on Neutral Value Scales and Equations Describing Them. I. H. GODLOVE, *Munsell Research Laboratory*. (20 minutes.)

The equations which have been proposed for the relation between "value" and reflection, and the possible reasons for the differences between the experimental results of Cobb and of this laboratory bearing on this relation, have been examined. New empirical equations were also examined. None of the previously proposed equations (Weber-Fechner, Delboeuf, Adams and Cobb—modified or unmodified, Plateau-Munsell) are in good agreement with the experimental data of this laboratory. A value scale computed from Cobb's data agrees very well with the M. R. L. data at middle value (when made to agree at the two ends); but at higher values requires lower reflectances and at lower values higher reflectances than the M. R. L. data, which were obtained by two totally different methods. Although the Adams and Cobb equation takes account of the reflectance of the background, an important condition, and fits very well the Cobb data for low values, it does not fit well the Munsell data; certain modifications of it give better agreement. A new empirical equation, containing the reflectance of the background and only one arbitrary constant, fits the Munsell data very well for both gray and white backgrounds (even though the constant be determined only to fit at the mid-gray point for the gray background), and assumes simple forms ($V^2=R$ and $V^2=mR+nR^2$) for particular backgrounds. For the experimental conditions of the work in this laboratory, the best fit to the data is given by an equation of a type intermediate between those of the Fechner-Delboeuf and Plateau-Munsell equations.

Bibliography:

A. E. O. Munsell, L. L. Sloan, and I. H. Godlove, *Munsell Neutral Value Scale*, J. O. S. A. 23 (1933).

6. The Establishment of a Color-Temperature Scale. H. T. WENSEL, D. B. JUDD, AND WM. F. ROESER, *Bureau of Standards*. (20 minutes.)

The temperature of a black body which color matches a given illuminant is called the color temperature of that illuminant. In accord with this definition, the direct visual comparison of an illuminant with a black body of known temperature is probably the most certain method of determining its color temperature; and this method has been extensively used in the establishment of the color-temperature scale heretofore used except for the higher temperatures. For the higher temperatures, due to difficulties of controlling the temperature of the black body, the method of visual comparison has been supplemented by less direct methods (red-blue ratio, spectral energy distribution). However, the type of black body recently used in the Waidner-Burgess standard of light[1] (a cavity immersed in a freezing metal) possesses a uniform and constant temperature susceptible of accurate determination. This type of black body makes possible the establishment of a color-temperature scale based entirely on direct visual comparison.

Projection lamps (400-watt) have been color matched against cavities immersed in freezing platinum, rhodium and iridium, and the voltages and currents measured. Nine lamps, three at each fixed point, have been color matched in this way. The temperatures of these fixed points had previously been determined as 2046, 2239 and 2727°K, respectively. These nine lamps, which have the status of primary lamp standards, were then compared with a group of three working standards so that we now have available a group of lamps the voltages and currents of each of which are known at each of the three color temperatures given above with an uncertainty of not more than 5°K.

The agreement between the color-temperature scale embodied in these lamps, and the scale of less certain basis used heretofore at the Bureau of Standards will be determined in time for presentation at the meeting.

[1] H. T. Wensel, Wm. F. Roeser, L. E. Barbrow, F. R. Caldwell, *The Waidner-Burgess Standard of Light*, Bur. Standards J. Research 6, 1103–1117 (1931).

7. A Filter for Producing the Color of the Equal-Energy Stimulus. R. DAVIS AND K. S. GIBSON, *Bureau of Standards*. (5 minutes.)

A filter has been designed which, in combination with a Planckian radiator at 2848°K, gives the color of the so-called equal-energy stimulus. The filter is of the same type as the other Davis-Gibson filters, the energy distribution matching the ideal to approximately the same degree as

those shown on charts 26 and 28 of Bureau of Standards Misc. Pub. No. 114.

The equal-energy stimulus has been adopted as the basic stimulus in the 1931 I.C.I. coordinate system. The present filter makes possible the general experimental realization of this color.

Bibliography:

Davis and Gibson, *Filters for the Reproduction of Sunlight and Daylight and the Determination of Color Temperature*, Bur. Stan. Misc. Pub. No. 114, 1931.

Gibson, *The Production of Radiant Energy of Uniform Intensity over the Visible Spectrum*, J. Opt. Soc. Am. and Rev. Sci. Inst. **13**, 305 (1926).

The present paper will appear in full in Bur. Standards J. Research.

8. Mass of the Neutron. ARTHUR BRAMLEY, *Bartol Research Foundation.* (15 minutes.)

Bothe and H. Becker found long range particles were emitted by Be^9 when bombarded by alpha-particles. Curie and Joliot found the surprising result that screens containing hydrogen enhanced the dissipation of energy of the primaries in contradiction to what we should expect for high energy photons. Ejection of protons by a Compton collision of photon and proton, would require the photons energy to be incredibly large. Chadwick[1] explained the results by supposing the primaries were neutrons of mass 1.0067.

A detailed investigation of the reactions into which the neutron enters has disclosed discrepancies in this assumption. Either the experimental results are subject to a larger error than we suspect or the neutrons are not as simple as we supposed. The data can be explained if we suppose (1) the mass of the neutron depends on the parent element and on the mode of disintegration of that element and (2) part of the mass of the neutron can be transformed in inelastic collisions as energy of the other nuclei. The first assumption is based on the values of the mass of the neutron. Curie and Joliot[2] propose the value 1.011 for the neutrons from Be^9; Chadwick[1] gives 1.0067 for those from B^{11} while Lawrence[3] gives evidence that the neutrons obtained when H^2 nuclei bombard Au have the mass 1.000.

The experiments on the disintegration of N^{14} by neutrons cannot be made consistent if the mass of the neutron is a definite fixed quantity.[4]

These examples suggest a dual nature for neutrons, the wave and particle aspects. On the wave theory we should expect the mass could be transformed in an analogous manner to that of a photon. Perhaps we should not speak of the binding energy of a neutron in the nucleus but treat it as associated with the nucleus in the same way a photon is associated with an excited atom.

[1] Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).
[2] Curie and Joliot, Comptes Rendus **197**, 237 (1933).
[3] Lawrence, Phys. Rev. **44**, 314 (1933).
[4] Harkins, Gans and Newson, Phys. Rev. **43**, 584 (1933). Kurie, Phys. Rev. **43**, 771 (1933). Feather, Proc. Roy. Soc. **A136**, 709 (1932).

The present paper will appear in full in J. Frank. Inst.

9. Seeing under Sodium Light. M. LUCKIESH AND FRANK K. MOSS, *Lighting Research Laboratory, General Electric Company.* (20 minutes.)

An adequate appraisal of the relative visual effectiveness of light from sodium vapor and tungsten filaments involves comparisons of the effects produced by these illuminants in the physical, physiological and psychological realms of seeing. This paper presents experimental data and fundamental theoretical considerations for comparing the efficacy of these illuminants for specific purposes.

Photometric measurements indicate that the average reflection-factor of a large variety of colored specimens is practically the same under both illuminants, although varying widely for individual colors. A comparison of the brightness-contrasts between various pairs of colors indicates that the sodium light enhances contrast in more cases than tungsten light does. In specific cases, the advantage of higher brightness-contrast may be on the side of either illuminant.

A comparison by physiological criteria also indicates that the advantage of one illuminant over the other depends upon the purpose for which the light is used. It is shown that monochromatic light from sodium vapor is definitely and significantly superior to the heterogeneous light from tungsten filaments for revealing detail of small colorless objects. The speed of retinal impression is also higher under the sodium light for objects of the order of 1 minute visual angle. This effect is probably closely correlated with the better definition of small objects under monochromatic light. Data on the speed of retinal impression are also presented for objects of the order of 10 minutes visual angle.

Pupillary measurements indicate that there is no detectable difference in pupil size when a small portion of the visual field is illuminated and that the pupil is slightly larger under sodium light when the entire visual field is illuminated. However, the differential in pupil size is too small to account for the difference in visual acuity under the two illuminants.

Measurements of nervous muscular tension, developed incidental to the task of reading, gave no indication of a difference in the behavior of the human seeing-machine under these two illuminants. These physiological results were obtained from subjects with normal vision.

Evidence is presented to show the influence of visual illusions on the appearance of objects illuminated with sodium light.

The present paper will appear in full in J. O. S. A.

10. Resolution Threshold of the Continuously Open Eye. SIDNEY M. NEWHALL, *Yale University.* (15 minutes.)

These experiments aimed (1) to discover what measurable effect, if any, prolonged lid-restraint might have on the resolution threshold, and (2) to trace, while the lid was restrained, the course of the resolution threshold with the passage of time.

The eye was kept open continuously by an eye-lid holder consisting essentially of a small adjustable bar by which the upper lid is prevented from occluding the pupil. The original model of the holder has been described.[1] The measure of the resolution threshold was the minimum visible as determined with the Ives crossed grating test object at a constant distance.

In the first experiment thresholds were secured before and after periods of lid-restraint; in some cases the lid was restrained for 10 to 15 min., in others for 20 to 25 min.

After the period of restraint the thresholds were higher than they had been before and than they were later.

In the second experiment threshold measurements were taken every minute throughout the period of restraint. Throughout this period of either 10 or 20 min. the thresholds were higher than were corresponding control thresholds without restraint. There is a slight tendency for the ratios of the experimental thresholds to the control thresholds, to rise with the passage of time suggesting progressive increase in effect.

In brief there is evidence that resolution thresholds for the continuously open eye are higher than otherwise. Probably a number of factors, including the means by which the eye is kept open, contribute to the observed effect.

[1] *The control of eyelid movements in visual experiments*, Am. J. Psychol. **44**, 563–565 (1932).

11. Measurements of Iris Pulsation in Binocular Flicker by Motion Photography with Ultraviolet Illumination. BRIAN O'BRIEN AND E. DICKERMAN O'BRIEN, *Institute of Optics, Rochester, N. Y.* (15 minutes.)

A horizontal mercury arc, imaged on the eyes of a subject through a filter system transmitting only the lines at 3650A, provided sufficient illumination for photographing the eyes on 35 mm film with a motor driven camera operating at six pictures per second. The subject was in visual darkness except for slight diffuse illumination of the retina due to fluorescence of the ocular media. Two identical visible fields illuminated with white light could be presented to the eyes by reflection from transparent glass plates through which the photographs were made, the fields being so adjusted as to readily fuse. Provision was made for flicker illumination of the two fields at equal frequency but with any desired phase relation between. The present study has been confined to very low flicker frequencies (of the order of ½ cycle per second) and rectangular wave form of the illumination cycle.

With illumination of the field of one eye only, the apertures of both irises pulsate at the frequency of flicker as expected, the pulsations lagging in phase behind the stimulus in amounts differing with different subjects, but in all cases the same for the illuminated as for the unilluminated eye. With the fields of both eyes illuminated, but 180 degrees apart in phase, both irises pulsate at double flicker frequency, apparently due to a short period fatigue effect, the amplitude of this double frequency pulsation varying widely among different individuals.

Pulsations due to blood pressure variation throughout the heart cycle were determined by photographing simultaneously a small neon lamp lighting on the first and extinguishing on the second heart sound. Control exposures without visible illumination showed that iris pulsations at heart frequency are very small except in certain subjects exhibiting a large differential pulse pressure.

12. Complementarism of the Standard (I.C.I. and O.S.A.) Observers. I. H. GODLOVE, *Color Service Laboratories, Washington, D. C.* (10 minutes.)

The wave-lengths of the complementary hues implied in the standard I.C.I. and O.S.A. color stimulus mixture data have been computed. In order to compare them with the experimental data of Sinden,[1] they have been computed so that mean noon sun (Davis-Gibson) was at the center of the mixture diagram. The I.C.I. data agreed better than the O.S.A. data with experiment. The data from 700 to 590 millimicrons agreed with the hypothesis that the I.C.I. observer has more macular pigment than the O.S.A., but for the region 400–470 millimicrons the reverse is true. The curves of complementaries are roughly parallel, instead of crossing, as they should if the whole difference were macular pigmentation. For most of the range both lie well within the crossing curves of Sinden's presumably most pigmented and least pigmented observers. By a method of "rectifying the hyperbolae," [2] equations describing the data, of the form $(\lambda - a)(b - \lambda') = c$ have been found. These reproduce the data to within an average of half a millicron. The constants for the I.C.I., O.S.A. and Sinden's own data, respectively, are: For a, 565.52, 569.74, 567.62; for b, 497.78, 494.04, 497.98; for c, 223.02, 164.46, 191.70.

[1] Sinden, J. O. S. A. and R. S. I. **7**, 1123–1153 (1923).
[2] Godlove, J. O. S. A. **20**, 411–418 (1930).

13. Standardization and Specification of Railway Signal Colors. K. S. GIBSON AND GERALDINE K. WALKER, *Bureau of Standards.* (15 minutes.)

In cooperation with the American Railway Association and Corning Glass Works, the Bureau of Standards is engaged in a spectrophotometric and colorimetric analysis of the glasses selected by the A.R.A. Signal Section to define the signal colors for American railroads. The Bureau's work has included:

1. Measurement of the spectral and luminous transmissions of 2-inch glass squares selected as duplicates to supersede the six A.R.A. standard roundels which have heretofore served to define the units of A.R.A. transmission.

2. Determination of the luminous equivalents of A.R.A. transmissions. The following values have been obtained:

Color designation of glass	A.R.A. transmission	Equivalent luminous transmission, 1931 I.C.I. Standard Observer, Illuminant 2360°K
Red	100.	0.069
Yellow	100.	.247
Green	100.	.119
Blue	100.	.0223
Purple	100.	.0129
Lunar white	100.	.189

3. Transmission measurements of glasses selected to define permissible limits, both of luminous transmission and of chromaticity, for the various signal colors.

4. Computation of the trilinear coordinates, x, y, z, for the various illuminant-glass combinations on the basis of the 1931 I.C.I. standard observer and coordinate system.

5. Preparation of tentative specifications for railway signal colors. The form of specification consists of giving (1) the limits of A.R.A. transmission for the glasses, (2)

values of x, y, and/or z for the illuminant-glass combinations, which serve to define certain areas on the (x, y)-plot of the mixture diagram, (3) the proportion of red to total luminous transmission, to differentiate between the blues and purples.

While the program outlined above has been completed, final specifications cannot be adopted until an investigation of duplicate limit glasses, now in progress, has been completed.

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Gage, *Practical Considerations in the Selection of Standards for Signal Glass in the U. S.*, Proceedings I. C. I., 1928, pp. 834–861.
Gibson and Walker, *Standardization of Railway Signal Glasses*, Signal Sect. Proceed., A. R. A., 1933, pp. 384–443.
Judd, *The 1931 I. C. I. Standard Observer and Coordinate System*, J. O. S. A. 23, October, 1933.

14. Filters for Testing the Reliability of Spectrophotometers. K. S. GIBSON, GERALDINE K. WALKER, AND MABEL E. BROWN, *Bureau of Standards.* (15 minutes.)

The Bureau is now prepared to issue glass filters for use as standards of spectral transmission, by means of which the accuracy of spectrophotometers may be tested throughout the visible spectrum. The report accompanying a filter includes (1) values of transmission at various wavelengths throughout the visible spectrum at 25°C, (2) the estimated uncertainty of each value, and (3) the temperature coefficient of change of transmission at each wavelength.

Four different kinds of glass have been used, cobalt-blue, copper-green, carbon-yellow, selenium-orange, twelve filters of each kind having been prepared. The filters are from 2 to 3 millimeters thick and approximately 30 mm in diameter.

About half of the filters have already been issued to applicants or reserved for special purposes; standardization of the others is in progress. The degree of agreement among the data obtained on the first six glasses of each kind, when reduced to a common thickness, has made possible the establishment of average values of $-\log_{10}$ transmittance having small uncertainty, from which the transmissions for the remaining filters can be computed. It is expected that check measurements at a few selected wavelengths will then justify the adoption (or very slight revision) of the computed values for these and the other wave-lengths.

Bibliography:

Gibson, *Spectrophotometry at the Bureau of Standards*, J. O. S. A. 21. 564–587 (1931).

15. Optical Problems Involved in a Comprehensive System of Bibliography. WATSON DAVIS, *Science Service.* (Introduced by E. C. Crittenden.) (30 minutes.)

The problem of adequate bibliography in science is not solved despite the time, effort, and money expended upon many diverse schemes in various branches of science. The author proposes a central scientific agency (tentatively referred to as Scientific Information Institute) that would compile and maintain a complete card bibliography of all scientific published material, past, present, and future, and distribute to research workers as required bibliography specially selected to meet specialized needs by a method essentially different from present bibliographical schemes.

The method requires: 1. Centralization of bibliography for economy and service. 2. Application of automatic finding and sorting devices to filing and selecting bibliography. 3. Rapid and inexpensive reproduction of selected items on demand.

These requirements can be met by development of technical processes already in existence, but the special adaptation to bibliographic purposes will require special research. Automatic electrical finding, sorting, and duplicating devices for punched cards are already widely used and photoelectric methods are being developed.

This paper is devoted to an assay of the optical and photographic problems which seem to be involved in a successful working of the method, and is presented in the hope that specialists working in these fields will contribute to the solution of some of these problems.

Rapid and inexpensive reproduction of selected items on demand seems to demand a photographic process; economy of filing space and low cost suggest microphotographic records and perhaps microphotographic reproduction.

Some of the questions raised are: (1) How great a reduction in size can be practically achieved through microphotography. (2) How practical is the suggestion of furnishing microphotographic reproduction for general use. This involves the problem of means for ready reading of microphotographic records. Can this be done most advantageously by a direct magnifying device or by projection? Can a practical reading machine be produced at a sufficiently low cost to allow its use as universally as the typewriter? Should the reproductions be on transparent or opaque backing? (3) What methods of reproduction can best be adapted to automatic photographic machinery? Should the records be on film, or sensitized paper, or can some photolithographic process be used?